OFFSHORE IMPACT ASSESSMENT

Esso Highlands Limited

PNG LNG Project

December 2008

An ExxonMobil Affiliate

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CONTENTS

Tables

Figures

Plates

Annexes

1. INTRODUCTION

1.1 Project Description

The Papua New Guinea Liquefied Natural Gas (PNG LNG) Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (LNG) for export. The development will also produce condensate. The development of the Hides, Angore and Juha gas fields and blowdown of the gas caps at the existing Kutubu, Agogo and Gobe oil fields will supply the gas resources. An extensive onshore and offshore pipeline network will enable transportation of the gas to a new LNG Plant near Port Moresby and stabilised condensate to the existing oil processing and storage, and offloading facilities at the Kutubu Central Processing Facility and Kumul Marine Terminal respectively. Small amounts of condensate are also produced at the LNG Facilities site.

Esso Highlands Limited (Esso), a Papua New Guinea subsidiary of the Exxon Mobil Corporation (ExxonMobil), is the operator of the PNG LNG Project. The PNG LNG Project will be developed in five phases over a period of 10 years to ensure reliability and consistent quality of supply of LNG over the 30 year life of the project.

A list of the proposed developments is provided below, and Figure 1.1 shows a schematic of facilities and pipelines:

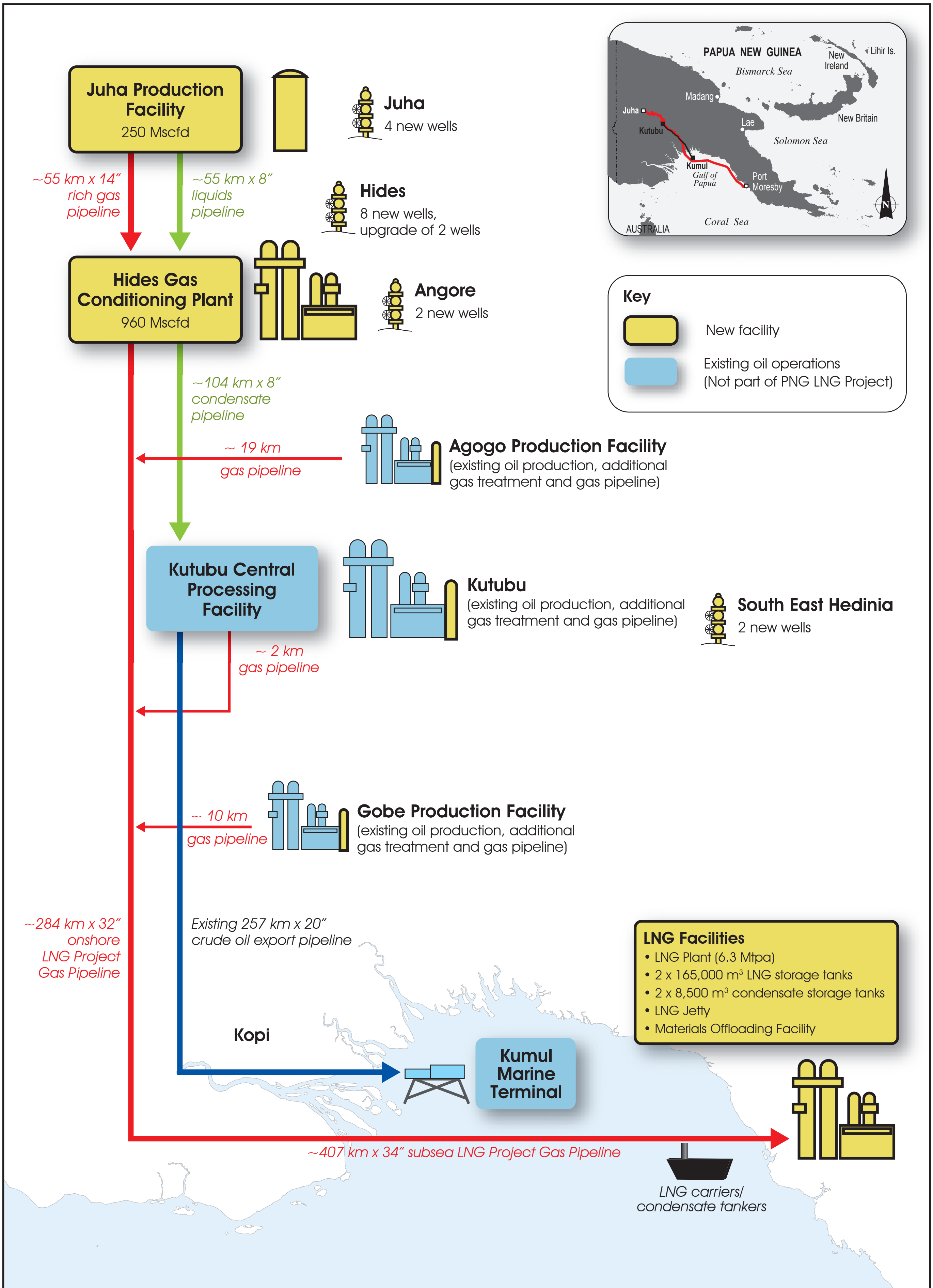
1.1.1 Upstream Development Components

- Hides gas field development:
  - Seven wellpads with a total of eight new wells and re-completion of two existing wells.
  - Hides gathering system including gas flowlines from new and re-completed Hides wells.
  - Hides spineline and mono-ethylene glycol (MEG) Pipeline in the same right of way (ROW).
  - Hides Gas Conditioning Plant.
  - Hides–Kutubu Condensate Pipeline in the same ROW as the LNG Project Gas Pipeline.

- Juha gas field development:
  - Three new wellpads with four new wells.
  - Juha gathering system including gas flowlines from new Juha wells.
  - Juha spinelines and MEG Pipeline in the same ROWs.
  - Juha Production Facility.
  - Juha–Hides pipelines right of way (ROW) containing three pipelines including Juha–Hides Rich Gas Pipeline, Juha–Hides Liquids Pipeline and Hides–Juha MEG Pipeline.

- Angore gas field development:
  - Two new wellpads with two new wells.
  - Angore gathering system including gas flowlines from new Angore wells.
  - Angore spineline and Angore MEG Pipeline to Hides Gas Conditioning Plant, both in the same ROW.

- Gas from existing fields:
  - Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline.



Note: Not to scale. Pipeline diameters are indicative only.

PNG LNG	Job No: 1284	Esso Highlands Limited	Project overview: new and existing facilities and pipeline	Figure No: 1.1
	File Name: 1284_07_F01.01_HB	PNG LNG Project		

  - Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline.
  - Gas treatment at the Kutubu Central Processing Facility and a new Kutubu Gas Pipeline from the Kutubu Central Processing Facility to the LNG Project Gas Pipeline.
  - South East Hedinia gas field development: one new wellpad and two new wells; new gathering system including gas flow lines from the South East Hedinia new wells to the Kutubu Central Processing Facility in the same ROW as the Kutubu Gas Pipeline.
- Kopi scraper station.
- LNG Project Gas Pipeline:
  - Onshore: from Hides Gas Conditioning Plant to Omati River Landfall.
  - Offshore: from Omati River Landfall to Caution Bay Landfall.

1.1.2 LNG Facilities Development Components

- Onshore LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities.
- Marine facilities including jetty, LNG and condensate export berths, materials offloading facility and tug moorage.

1.1.3 Supporting Facilities and Infrastructure

In addition to the principal gas production, processing and transport, and LNG production and export facilities, the project will involve the following permanent infrastructure and facilities:

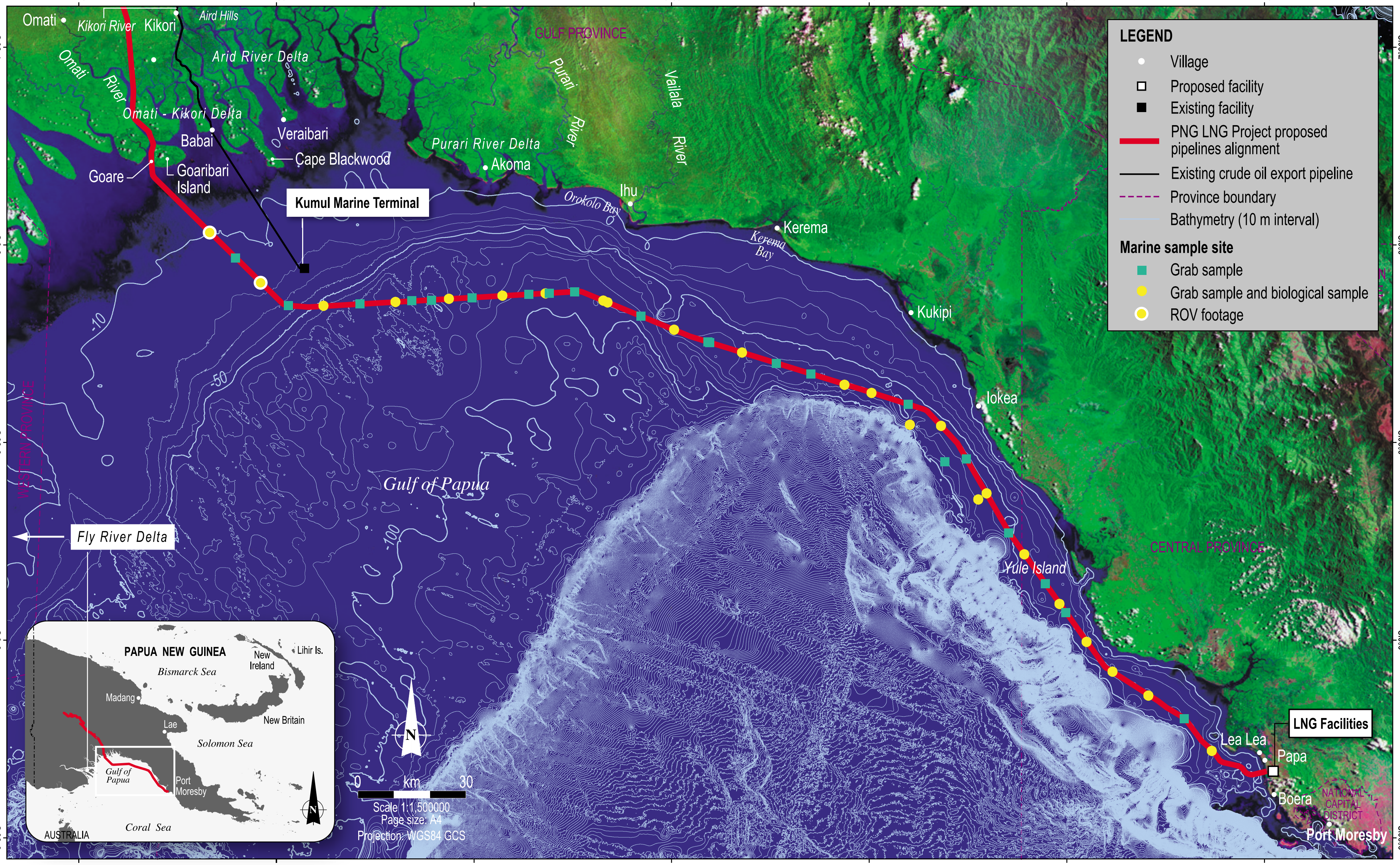
- New roads and upgrade of existing roads.
- New bridges and upgrade of existing bridges.
- Upgrade of two existing airfields (upstream at Komo and Tari).
- New helipads (multiple).
- New wharf and an upgrade of the existing Kopi roll-on, roll-off facility.
- Water supply systems and pipelines, wastewater and waste management facilities.
- Operations Camps (at Hides, Juha and Tari).

A series of temporary works and access roads will also be required during the construction phase, including:

- Construction camps (multiple).
- Material/pipe laydown areas.

1.1.4 Project Components Relevant to this Study

This study focuses on the offshore section of the LNG Project Gas Pipeline. This section of the pipeline is approximately 407 km in length and traverses the Gulf of Papua from the Omati River to Caution Bay (Figure 1.2). The proposed offshore pipeline route follows the Omati River into the Gulf of Papua. Once the pipeline is in the Gulf, it is routed around the Kumul Marine Terminal and associated pipeline on the southwestern side and then across the Gulf of Papua and into Caution Bay to a point immediately north of the LNG Plant. The point where the pipeline enters the Omati River is called the Omati River Landfall and the point where it crosses the Caution Bay shoreline is called the Caution Bay Landfall.



Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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Offshore pipeline route, bathymetry and marine pipeline survey sampling locations

Figure No: 1.2

Installation of the offshore pipeline is expected to involve several vessels, including a pipelaying vessel (anchored laybarge or dynamically positioned laybarge), anchor-handling tugs (depending on pipelaying vessel type), a general supply vessel, pipe supply vessels, bulk carriers (to transport pipe to a location from which the pipe supply vessels can supply pipe to the pipelaying vessel), a dedicated survey vessel and an accommodation vessel.

The pipeline will be laid onto the seafloor along the majority of the proposed route, where a combination of its inherent weight (provided by a concrete coating) and self-burial in areas of softer sediment will provide the necessary pipeline stability. Where the seafloor is hard or the sediments are thin, the pipeline may only partially self-bury. Localised sections of the pipeline could then become unsupported (called spanning) if strong lateral currents scour the seafloor underneath the pipeline. In these areas, span reduction methods, such as trenching or grout bag support, will be employed. The pipeline will also be trenched in the Omati River (including a distance beyond the river mouth) and near the landfall in Caution Bay for protection against impacts from vessels and anchors. Trenching techniques include dredging, cutting, ploughing and jetting. It is these activities that cause the most seafloor disturbance.

This study also discusses the issues associated with barges, that are proposed to transport project-related supplies from Port Moresby across the Gulf of Papua and through the Omati-Kikori delta to Kopi over a 3-year period at an average frequency of approximately 2.7 trips per week.

1.2 Purpose of this Document

This report summarises the physical (Section 2), biological (Section 3) and resource utilisation (Sections 4 and 5) characteristics of the offshore marine environment crossed by the proposed offshore pipeline through the Gulf of Papua. Potential issues associated with the construction and operation of the offshore pipeline and barge traffic are described and assessed in Section 6. Recommendations on measures that could be implemented to mitigate these issues are described in Section 7. A summary of the potential issues, issue assessment and recommendations is provided in Section 8.

The geographic scope of this assessment is limited to the Omati River and offshore marine environment i.e., from the Omati River Landfall, downriver to the mouth of the Omati River and across the Gulf of Papua to the outer edge of Caution Bay. The nearshore marine environment of Caution Bay is addressed in a report titled *Nearshore Impact Assessment* (Coffey Natural Systems, 2008a), which is an appendix to the PNG LNG Project EIS. Further information about resource utilisation in the Omati River is also provided in a report titled *Resource Use Survey of the Omati-Kikori Delta* (Coffey Natural Systems, 2008b), which is also an appendix to the PNG LNG Project EIS.

1.3 Methods and Sources of Information

Methods and sources of information used to describe the marine environment are summarised as follows:

- Review of recent scientific literature on the oceanography and sediment transport in the Gulf of Papua (e.g., Wolanski et al., 1995; Petr, 1983 and Hemer et al., 2004).
- Review of scientific information on the current status of commercial fisheries in the Gulf of Papua (e.g., Koren, 2004a, 2005, 2006; and ACIAR, 2006).
- Discussions with the National Fisheries Authority (NFA) in Port Moresby in 2005 (NFA, pers. com., 2005).

- Discussions with Augustine Mobiha from of the NFA in Port Moresby in April 2008 (Mobiha, pers. com., 2008).
- Discussions with Mr Karme, Mr Kabilu and Mr Tavul from PNG Ports Corporation in December 2007 (Kabilu, pers. com., 2007).
- Historical information and photographs of catches and by-catches taken from prawn trawlers operating in the Gulf of Papua during the period from 1978 to 1980 (e.g., Gwyther, 1980, 1982).
- Specialist report prepared by Curtin University (2008) (Annex A) that predicts underwater noise produced by pipelaying operations in the Gulf of Papua and its likely effects on marine animals.
- Specialist report prepared by Coffey Natural Systems (2008b) that describes resource utilisation in the Omati–Kikori Delta.
- Results from a survey of the offshore pipeline route, which included underwater video photography and benthic grab sampling. Details of survey methods are provided below.

1.3.1 Marine Pipeline Survey

Characterisation of the seafloor habitats along the offshore pipeline route was achieved during a field survey conducted in March and April 2008 using a combination of the following methods:

- Sediment collection and description.
- Analysis of infauna.[1]
- Underwater video photography.

The survey was undertaken by Coffey Natural Systems (Coffey) using the survey vessel, the Pacific Conquest (Plate 1.1) in conjunction with geophysical and bathymetric investigations, which were undertaken by EGS Survey Pty Ltd (EGS).

The findings of the survey undertaken by Coffey are summarised in this report. Details of the infauna analysis are provided in Annex B.

Sediment Collection

Sediment grab samples were collected using a Van Veen grab sampler (with a scoop volume of 0.3 m^3), as shown in Plate 1.2, every 10 km along the proposed pipeline route as part of the geophysical work undertaken by EGS (Table 1.1, Figure 1.2). Sediment sub-samples were taken from selected locations for biological characterisation of sediments (see below). The sediment was described in terms of colour, texture and grain size by EGS and these results are provided in Section 2.5.

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[1] Aquatic animals that live within the bottom substratum rather than on its surface.

Source: T. Hart

Plate 1.1 Pacific Conquest


Source: N. Goldsmith

Plate 1.2 Grab sampler


Source: N. Goldsmith

Plate 1.3 Sediment sifting

Source: N. Goldsmith

Plate 1.4 VideoRay Pro III

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Table 1.1 Marine pipeline survey sampling locations

Site Number	Location*		Water Depth (m)	Infauna Sample Collected	ROV** Footage Taken
	Easting (m)	Northing (m)			
1	205967	9118178	10	Yes	Yes
2	213146	9111172	11	No	No
3	220306	9104255	14	Yes	Yes
4	227975	9097920	32	No	No
5	237787	9097829	55	Yes	No
6	247929	9098470	71	No	No
7	257855	9099072	85	Yes	No
8	262331	9099514	73	No	No
9	267872	9099617	96	No	No
10	272799	9099995	80	Yes	No
11	279218	9100370	90	No	No
12	287705	9100946	75	Yes	No
13	294999	9101433	95	No	No
14	299702	9101669	107	Yes	No
15	300750	9101799	103	No	No
16	307766	9102190	93	No	No
17	315809	9099729	88	Yes	No
18	317017	9099204	93	Yes	No
19	326280	9095429	86	No	No
20	335584	9091623	66	Yes	No
21	345019	9088298	63	No	No
22	345504	9088113	63	No	No
23	354537	9085352	57	Yes	No
24	364104	9082382	64	No	No
25	373707	9079471	67	No	No
26	383164	9076408	74	Yes	No
27	390704	9074130	72	Yes	No
28	401383	9065238	83	Yes	No
29	411066	9054977	84	No	No
30	420465	9044413	74	Yes	No
31	400869	9071003	66	No	No
32	410072	9064955	62	Yes	No
33	417092	9055755	66	No	No
34	422767	9046105	66	Yes	No
35	428935	9035140	59	No	No
36	433329	9029109	49	Yes	No
37	439098	9020988	38	No	No

Table 1.1 Marine pipeline survey sampling locations (cont'd)

Site Number	Location*		Water Depth (m)	Infauna Sample Collected	ROV** Footage Taken
	Easting (m)	Northing (m)			
38	443152	9015203	42	Yes	No
39	444859	9012848	38	No	No
40	450656	9004656	38	Yes	No
41	457864	8996282	47	Yes	No
42	467876	8989628	45	Yes	No
43	477809	8983241	45	No	No
44	485516	8974156	32	Yes	No

* Coordinates in WGS84 UTM Zone 55 S.

** Remotely Operated Vehicle.

Infauna

Infauna was extracted from approximately half of the sediment samples collected during the survey (see Table 1.1, Figure 1.2). Infauna sampling sites were selected to cover all water depths encountered along the proposed pipeline route and at least one sample was collected every 30 km along the route. Additional sampling was undertaken in areas of interest identified using detailed bathymetric data collected by EGS during the survey.

The contents of the grab sampler were emptied directly into a large plastic tub and seawater was added. The sediment/water mixture was then manually agitated and the water was passed through a 0.5 mm sieve; a process called elutriation, which works on the principle that animals are lighter than sediments and float off more easily.

In addition, two 'scoops' of the solid sediment (approximately four litres) were passed through the sieve (Plate 1.3). The presence of a relatively high fraction of sticky clays in the sediment samples meant that they were difficult to pass through the sieve, consequently a gentle jet of water was used to break up the clay, however, care was taken not to damage the animals with excessive water pressure.

The infauna and sediment retained in the 0.5 mm sieve was preserved in 70% ethanol and stored in plastic sample jars. The samples were sent to Dr John Moverley in Melbourne for identification. Animals were separated into vials of common phyla (crustacea, worms and molluscs) and identified to the lowest possible taxonomic level possible (to at least family level) without the use of reference material.

Identification and counts were made under a dissecting microscope. Sample material has been retained if lower taxonomic identification is required in the future. The infauna results were then subject to multivariate statistical analyses of communities, using ordination routines contained in the computer program Plymouth Routines In Multivariate Ecological Research (PRIMER), developed by Plymouth Marine Laboratory, UK (Clarke, 1993; Clarke & Warwick, 1994; Clarke & Gorley, 2001). The raw data and results of the analysis are provided in Annex B and summarised in Section 3.1.1.

Underwater Video Photography

The survey intended to obtain video footage of the seafloor at all of the infauna sampling sites, however, due to mechanical problems with the video equipment, video footage was only collected from two sites near the mouth of the Omati River (see Table 1.1, Figure 1.2).

Video footage of the seafloor was obtained using VideoRay Pro III (Plate 1.4), a digital video camera housed in a remotely operated vehicle (ROV) with an umbilical cable connected to an onboard control unit for real time viewing. The ROV control unit is fitted with a compass and depth display and a monitor to allow the user to navigate along the seafloor.

Video footage was recorded to digital videotapes and later transferred to DVD to allow for editing and extraction of still images, which are provided in Section 3.1.

2. PHYSICAL ENVIRONMENT

2.1 Physiography

The Gulf of Papua forms an area of approximately 50,000 km^2 bordering the southern coast of PNG. The Gulf shoreline is a low-lying swampland of the delta complexes of large rivers draining the mountainous highlands of central PNG. The Fly, Kikori and Purari rivers discharge huge volumes of fresh water (15,000 m^3/s in total) (Wolanski et al., 1995) and sediment (350 Mt/yr in total) (Wolanski et al., 1984, cited in Harris et al., 1996) into the Gulf of Papua. The Purari River is the third largest river in PNG and contributes a mean flow of 2,360 m^3/s; while the Kikori River contributes about 1,500 m^3/s into the Gulf (Petr, 1983).

The proposed offshore pipeline route through the Gulf of Papua traverses two geomorphic zones:

- A prodelta associated with sediment accumulation and coastal progradation. Local short-term erosion and accretion is substantial, with organic material derived from the land ranging in size from small fragments of vegetation to submerged trees sometimes encountered in various stages of burial and decomposition.
- The edge of a continental shelf, which becomes less affected by the sediment influxes from the prodelta as it continues eastward.

2.2 Bathymetry

The proposed offshore pipeline route runs along a continental shelf and does not traverse water depths greater than approximately 100 m (see Figure 1.2).

Outward from the Omati–Kikori delta complex, the continental shelf extends 160 km from the river mouth, where it drops dramatically to depths of greater than 100 m. The seafloor is relatively flat on this part of the continental shelf due to the sediment influxes from the river systems. The continental shelf becomes narrower as it continues eastward along the PNG coast, away from the influence of the Omati and Kikori rivers and other major rivers of the Gulf, and is approximately 20 km wide near Caution Bay.

2.3 Climate

2.3.1 Winds

Wind patterns in the Gulf of Papua are seasonal (NSR, 1990; Williams, 1994; Woolfe et al., 1997). The two wind regimes that influence climate within and along the coast of the Gulf of Papua are:

- *Northwest monsoon* (November to April) winds are predominantly from the northwest or west and generally less than 31 km/h (17 knots), with wind speeds exceeding this only 15% of the time.
- *Southeast trades* (May to October), predominantly from the southeast, exceed 31 km/h (17 knots) for 30% of the time in the Gulf of Papua (NSR, 1990).

Between the two main seasons are transitional periods of calm weather (doldrums).

Gubas are short-lived squalls of about 1 hour's duration, with wind speeds of 55 to 65 km/hr (30 to 35 knots), which occur during the northwest monsoon in the Gulf of Papua. They can sometimes be associated with thunder, lightning and precipitation and are a common feature of equatorial weather. Port Moresby experiences *Gubas* about five times a year (McAlpine et al., 1983).

2.3.2 Cyclones

The Gulf of Papua is an area of low to moderate cyclone risk. The cyclones generate storm-force winds and long-period waves in the Gulf of Papua, and substantial seafloor scouring and sediment movement most often occur in shallow waters under these conditions. Cyclones occur mainly during the period from February to April, however Tropical Cyclone Guba occurred in mid-November 2007.

Tropical Cyclone Guba formed in the Coral Sea and skirted the south coast of mainland PNG, including the Gulf of Papua. During this time peak winds reached 140 km/h.

2.3.3 Temperature and Rainfall

Meteorological stations located at Port Moresby (on the eastern side of the Gulf of Papua) and Daru (on the western side of the Gulf of Papua) are the closest long-term sources of meteorological data for the Gulf of Papua.

Temperature does not vary greatly in Port Moresby. January and December are the hottest months, with the average daily temperature minimum and maximum being 24°C and 32°C. The average daily temperature minimum and maximum in the coolest months (July and August) are 23°C and 28°C (BBC Weather, 2006).

Temperatures at Daru are similar to those at Port Moresby. The hottest month is January when the average daily temperature minimum and maximum are 27°C and 31°C. The average daily temperature minimum and maximum are 24°C and 28°C and occur during the coolest month of July (MSN Weather, 2008).

Rainfall in PNG varies greatly from place to place due to the range of altitudes and exposure to the seasonal wind patterns. Annual rainfall across most areas of PNG ranges from about 2,000 to 3,000 mm per annum, although higher rainfall (i.e., 5,000 mm per annum) occurs at high altitudes. Port Moresby is one of the driest areas in PNG and receives an average annual rainfall of 1,125 mm (BBC Weather, undated).

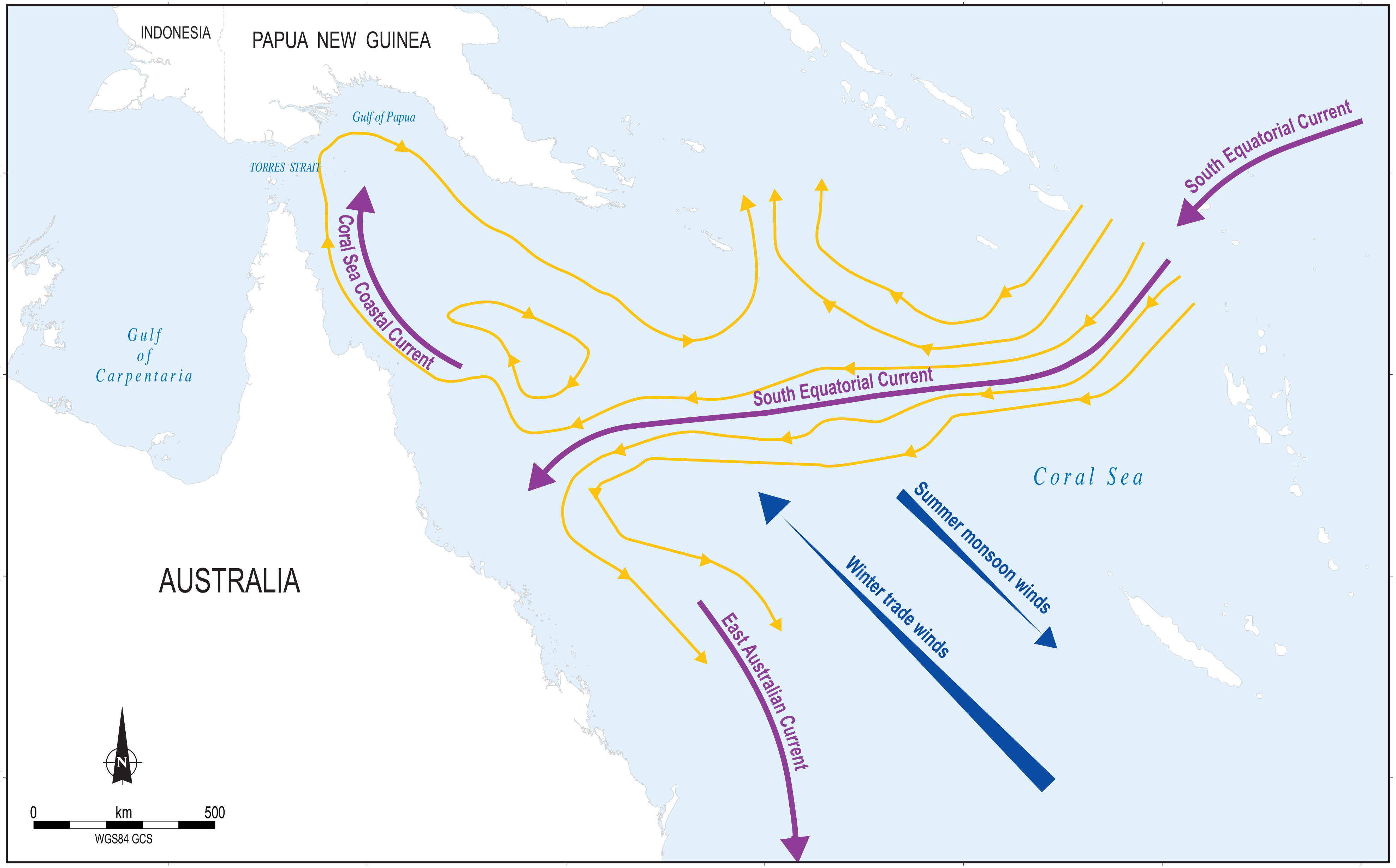
2.4 Oceanography

2.4.1 Tides

Tides in the Gulf of Papua are semi-diurnal to mixed. A maximum spring tidal range of 4 m and mean spring tidal ranges of 2.5 to 3 m occur in the western gulf (Wolanski & Eagle, 1991, cited in Woolfe et al., 1997). Tidal ranges in the eastern extent of the gulf tend to be smaller, with a mean spring tidal range of less than 3 m.

2.4.2 Currents

Oceanic circulation within the Gulf of Papua is dominated by a clockwise gyre, generated as the northwards-flowing Coral Sea Coastal Current enters the Gulf along the eastern edge of the Torres Strait and exits to the northeast (Woolfe et al., 1997) (Figure 2.1). As a result, most of the freshwater (and sediment) delivered to the Gulf by the large Papuan rivers travels eastwards. During the southeast trades season, short-term periods of strong winds can drive nearshore surface waters to the west for a number of days (King, pers. com., 2008).



Source:
Burrage et al. (1993) as cited in Woolfe et al. (1997)

PNG LNG	Job No: 1284	Esso Highlands Limited	Oceanic circulation in the Gulf of Papua	Figure No: 2.1
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2.4.3 Waves

The Gulf of Papua is exposed to the local surface waves generated by winds during the southeast trades. These waves propagate in the general southeast direction of the winds along the coastline of the Gulf of Papua but refract across shallow waters toward the shoreline.

During the northwest monsoon, the offshore winds result in little or no wind driven swell. During the southeast trades, the seasonally averaged significant wave height[2] reaches 1.5 m relatively close to the coast (Hemer et al., 2004).

2.4.4 Sediments and Sedimentation

The Gulf of Papua has very high suspended sediment loads that originate from:

- High suspended sediment loads discharged from the Fly, Omati, Kikori and Purari rivers into the Gulf of Papua.
- Continuous reworking of sediments by strong tidal currents and wave action.
- Fluid-mud bodies, which flow along the deepest parts of the subsea channels as dense, mobile, near-bed suspensions, typically around 1 m in thickness (observed to the west, off the Fly River.

Concentrations of fine-grained suspended sediment rarely fall below 500 mg/L within the river mouths and the Fly River Delta but can reach from 10,000 mg/L to a maximum recorded of 40,000 mg/L in fluid-mud layers, which take around 35 hours to travel across the 20-km–wide, low-gradient delta front off the Fly River (see Harris et al., 2004; Dalrymple et al., 2003).

Turbid brackish plumes are often present and can extend as far as 50 km offshore (Plates 2.1 and 2.2). Forest debris transported by the rivers is also present in varying amounts in these plumes and was observed during the marine pipeline survey in March and April 2008 (Plate 2.3). Waters are generally clear towards the eastern side of the Gulf, away from the influence of large rivers.

Several studies have investigated the fate of modern sediment supplied by the rivers entering the Gulf of Papua, particularly the Fly River (see Nittrouer et al., 2005[3]). These have investigated processes involved in transport (Harris et al., 2002, 2004; Hemer et al., 2004), sedimentology (Dalrymple et al., 2003) and deposition (Nittrouer et al., 2005). All play some part in explaining how sediment is delivered to the rapidly accreting prodelta.

Coring data, remote imagery and comparisons of bathymetric charts over the past 50 years show sedimentation rates of 1 to 2 cm/yr on the delta front and in the order of 4 cm/yr on the prodelta (Harris et al., 1996, 2004). Even higher deposition has been recorded on the prodelta when bodies of fluid mud settle (Walsh et al., 2000 as cited in Harris et al., 2004). While the number of islands has changed and islands have moved, the overall area of islands and distributary channels has remained constant (Baker, 1999 as cited in Harris et al., 2004). This suggests that the overall shape of the distributary channels is in dynamic equilibrium with the tidal regime and that the seaward progradation of the delta front (approx 6 m/a, stated in Harris et al., 1996) is matched by the seaward transition of the mainland coast.

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[2] The average height (trough to crest) of the largest one-third of waves.

[3] Seafloor research in the Fly River delta area by the University of Washington Marine Geology and Geophysics Group (MGG) and other collaborating academic agencies as part of the Margins program funded by the US National Science Foundation (see Margins Website).

Plate 2.1 Turbid surface plumes in the Omati-Kikori delta

Plate 2.2 Turbid outflow from the Omati-Kikori delta

Plate 2.3 Forest debris in Gulf of Papua near Omati–Kikori delta

The mechanisms of sedimentology of the Gulf of Papua are influenced by fall-out from buoyant plumes, tidal resuspension and advection from waves and wind-generated currents, and via the dense, bottom-attached mud-flows across the shelf. The recent studies have identified the clinoform structure by which sediment is stored and the delta front advanced. The clinoform morphology is a sigmoidal (or S-shaped) bathymetry with gently dipping topset on the middle shelf where the sediment is first deposited, leading to a steeply sloping foreset and gentle bottomset. In continental margins dominated by rapid sediment accretion (such as in the Gulf of Papua), this clinoform is the prevailing morphology. It is evident at broad scale in the regional bathymetry of the Gulf of Papua (see Figure 1.2), with the gently dipping nearshore shelf (the topset) and the steep foreset between the 30 to 50 m contours.

Descriptions of the sediment collected along the pipeline route as part of the marine pipeline survey in March and April 2008 (see Section 1.3.1) are provided in Table 2.1.

Table 2.1 Description of sediments collected along the offshore route

Site Number	Description of Sediment
1	Very soft light olive grey, CLAY
2	Very soft olive grey slightly silty fine SAND
3	Very soft olive grey slightly silty fine SAND
4	Very soft olive grey fine CLAY
5	Very soft olive grey fine CLAY
6	Very soft olive grey CLAY
7	Very soft light olive grey slightly silty CLAY
8	Very soft light olive grey slightly sandy SILT
9	Very soft light olive grey silty CLAY
10	Very soft olive grey slightly sandy SILT
11	Very soft light olive grey slightly silty CLAY
12	Very soft medium grey slightly silty CLAY
13	Very soft medium grey CLAY
14	Very soft medium grey slightly silty CLAY
15	Very soft medium grey slightly silty CLAY
16	Very soft medium grey slightly sandy CLAY
17	Soft medium brown well sorted slightly sandy gravely CLAY
18	Very soft medium grey CLAY
19	Very soft medium grey CLAY
20	Very soft medium grey slightly sandy silty CLAY
21	Very soft medium brown slightly silty gravelly CLAY
22	Very soft medium brown slightly silty gravelly CLAY
23	Very soft olive grey slightly silty slightly gravelly Medium SAND
24	Very soft greenish grey slightly gravelly sandy SILT
25	Very soft greenish grey slightly sandy SILT
26	Very soft dark greenish grey slightly silty CLAY
27	Dark greenish grey slightly silty CLAY
28	Very soft dark greenish grey slightly silty CLAY
29	Dark greenish grey very soft slightly silty CLAY

Table 2.1 Description of sediments collected along the offshore route (cont'd)

Site Number	Description of Sediment
30	Very soft dark greenish grey slightly silty CLAY
31	Very soft dark greenish grey slightly silty CLAY
32	Very soft dark greenish grey slightly silty CLAY
33	Very soft dark greenish grey slightly silty CLAY
34	Dark greenish grey very soft slightly silty CLAY
35	Very soft dark greenish grey slightly sandy SILT
36	Very soft dark greenish grey slightly sandy silty CLAY
37	Very soft olive grey gravelly SAND
38	Very soft dark greenish grey slightly gravelly slight sandy SILT
39	Very soft medium grey silty SAND
40	Very soft medium grey CLAY
41	Very soft medium grey CLAY
42	Very soft medium grey slightly silty CLAY
43	Dark greenish grey very soft slightly silty CLAY
44	Very soft dark greenish grey slightly gravelly silty medium SAND

2.5 Underwater Noise

The principal sources of ambient ocean noise in the Gulf of Papua are likely to be:

- Natural physical sources, such as air–ocean interaction and other oceanic processes.
- Natural biological sources, such as the sounds made by whales and dolphins.
- Man-made sources, such as shipping activities.

2.5.1 Natural Physical Sources

Ambient background noises are given in a review by the National Research Council of the National Academy of Sciences (NRC, 2003) and are summarised below. The dominant source of naturally occurring noise across the band frequencies from 1 to 100 Hz is associated with ocean surface waves generated by wind. Average ambient noise levels of 98 dB, 20 to 1,000 Hz have been determined in the Canadian Beaufort Sea (Richardson et al., 1990). During the northwest monsoon period when seas in the Gulf of Papua are generally calm, noise levels from wind would be expected to be at the lower end of the range. Below 5 to 10 Hz, the dominant ambient source is non-linear interaction of oppositely propagating ocean surface waves (called microseisms). Above 100 Hz, thermal noise caused by the pressure fluctuations associated with thermal agitation of the ocean is the dominant contributor. Across the remainder of the band, the main sources are bubbles oscillating individually or collectively in the water column.

Meteorological processes that may be experienced in the project area vary in frequency and are largely dependent on seasons. Sources of noise such as raindrops on the sea surface can increase the ambient noise levels by up to 35 dB across a broad range of frequencies extending from several hundred hertz to greater than 20 kHz. Thunder and lightning has characteristic spectra peaks between 50 and 250 Hz, and peaks up to 15 dB above ambient levels have been recorded 5 to 10 km away.[4] Seismic energy from geological and tectonic sources can travel over great distances, extending to frequencies higher than 100 Hz with sharp onset and variable duration.

2.5.2 Natural Biological Sources

Marine animals such as whales, dolphins, fish and invertebrates are responsible for creating biological noise associated with communication, navigation, echolocation and feeding strategies. Biological sources make contributions to the ambient ocean noise at certain seasons or periods of the day.

Marine mammal vocalisations are associated with behavioural adaptations and cover a wide range of frequencies. Odontocetes (dolphins and toothed whales) produce broadband clicks that are characteristic of species, and cover a wide energy range from less than 10 Hz to more than 200 kHz (NRC, 2003). Vocalisations of mysticetes (baleen whales) are significantly lower in frequency than those of odontocetes and are broadly categorised as low-frequency moans. Peaks around 20 Hz, created by calls of large baleen whales are often present in deep ocean noise spectra. However, there are a wide variation of calls and songs, potentially used in long-distance communication and topological echolocation (NRC, 2003).

Source levels for whale and dolphin vocalisations have been reported as high as 228 dB re1µPa for echolocation of false killer whales (Thomas & Turl, 1990, cited in NRC, 2003) and bottle-nosed dolphins echolocating in the presence of noise (Au 1993, cited in NRC, 2003). The highest levels are calculated at 232 dB re1µPa for adult male sperm whales (Møhl et al*.,* 2000, cited in NRC, 2003). Such high source levels are required for acoustic imaging of the environment using return echoes from objects with low target strength. The short duration of the echolocating clicks (50 to 200 µs) means that the energy content integrated over time is low, even though the source levels are high (Au, 1993, cited in NRC, 2003). Baleen whale vocalisations have the potential to be detected over long distances because of their low frequencies. Blue whales and fin whales produce low frequency (10 to 25 Hz) moans with estimated source levels up to 190 dB re1µPa (NRC, 2003). Vocalisations below 1 kHz and source levels above 180 dB re1µPa have also been recorded for other large baleen whales such as bowhead, southern right and humpback whales (Richardson et al., 1995). Humpback whales can significantly increase background noise during breeding season. Time-averaged peak levels recorded 2.5 km offshore (Hawaii) reached 125 dB re1µPa (NRC, 2003) and the baleen whales can be detected over the longest distances.

The diversity of fish inhabiting the Gulf of Papua may also contribute to the ambient noise levels. Many species of marine fish and invertebrates produce sound and use it primarily for communication. Fish produce sounds by means such as striking bony structures against one another, or by muscle movement amplified by the gas-filled swim bladder (NRC, 2003). Many species participate in regular chorusing behaviour (when a large number of individuals call simultaneously), often at dawn or sunset, with characteristic peak frequency of 1 KHz at broadband levels of 86 dB re 1 µPa (APPEA, 2005). Snapping shrimps are capable of generating very distinct broad peaks within the 2,000 to 15,000 Hz frequency bands by snapping closed their large front claw (McCarthy, 2004).

[4] NRC (National Research Council of the National Academy of Sciences) 2003. Ocean Noise and Marine Mammals. The National Academic Press, Washington, D.C. (http://www.nap.edu./openbook0309085365).

2.5.3 Man-made Sources

Commercial shipping is a major contributor to ambient noise levels, especially at low frequencies between 5 to 500 Hz (NRC, 2003). Low frequency ship noise sources include propeller noise (cavitation, blade frequency and blade passage forces), hydrodynamic hull flow, engines and other machinery. The noise of merchant shipping falls into two categories. First, the noise of distant traffic that is not really audible as a ship but contributes to elevated sea noise levels across a defined frequency range affecting large geographic areas. Second is noise from nearby traffic that is identifiable as such. Sound levels and frequency characteristics are roughly related to ship size and speed, but vessel signatures can be specific. Richardson et al. (1995) reports data from commercial vessels from literature sources. Noise levels measured for the larger class vessels (e.g., supertankers) are highest, with a recorded value of more than 180 dB, at the lower frequency band of 20 Hz. Chapter 5 describes the shipping activities in the Gulf of Papua.

3. BIOLOGICAL ENVIRONMENT

3.1 Habitats and Seafloor Characteristics

This section is primarily based on a report written by EGS (2008) following their participation in the marine pipeline survey and observations made by Coffey personnel during the same survey.

At the mouth of the Omati River in the vicinity of Goaribari Island, water depth is approximately 6 m. The shoreline is lined with vegetation, including nypa palms (*Nypa fruticans*) and reeds (*Phragmites* sp.) (Plate 3.1), and the seafloor in this area is comprised almost entirely of very soft clays and silts.

Water depths increase to approximately 30 m as the proposed pipeline route travels 50 km southeast to a point just south of the Kumul Marine Terminal. The substrate composition along this section of the pipeline route consists of very soft clays and silts, with some sand megaripples.[5]

Once south of the Kumul Marine Terminal the proposed route heads east along the continental shelf, where water depths along this 90-km–long pipeline section gradually increase to approximately 90 m. Seafloor sediment composition in this section varies from very soft clay to well-layered interbedded sand, silt and clay layers. Sandwaves, 1.5 to 2 m in height with wave lengths of approximately 150 to 180 m, are present in this section of the route, along with shallow seafloor depressions typically several tens of metres across and a few metres deep

The next section of the proposed pipeline route running to the east-southeast for approximately 100 km gradually changes in water depth from 90 m to 60 m. The seafloor along this section of the proposed route is composed of very soft, slightly silty clay layers 1 to 12 m thick. Rock outcrops were observed along this section, surrounded by slightly clayey, slightly sandy gravel. Some parts of this section are characterised by shallow seafloor depressions.

The remaining section of the proposed pipeline route runs in a southeasterly direction parallel to the coastline and water depths along the proposed route decrease from 60 to 35 m at the outer edge of Caution Bay. The seafloor is mostly composed of slightly silty clay substrate although rock outcrops also occur.

The marine pipeline survey undertaken in March and April 2008 along the proposed offshore pipeline route did not identify any communities of seagrass or corals. Seafloor along the proposed route occurring at depths shallow enough to support seagrass and corals is limited to areas near the Omati River and Caution Bay.

Near the Omati River end of the proposed pipeline route, high levels of suspended sediment (Plate 3.2) prevent the establishment of seagrass habitats, which rely on sunlight for photosynthesis. The seafloor here consists of very soft clays and silts that are unsuitable for establishment of coral communities.

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[5] Undulations produced on the seabed by fluid movement (waves and currents) over sediments, generally with wavelengths of 0.5 to 25 m.

Plate 3.1 Nypa palms and reeds in the Omati River

Plate 3.2 ROV footage showing high levels of suspended sediment near the Omati River mouth

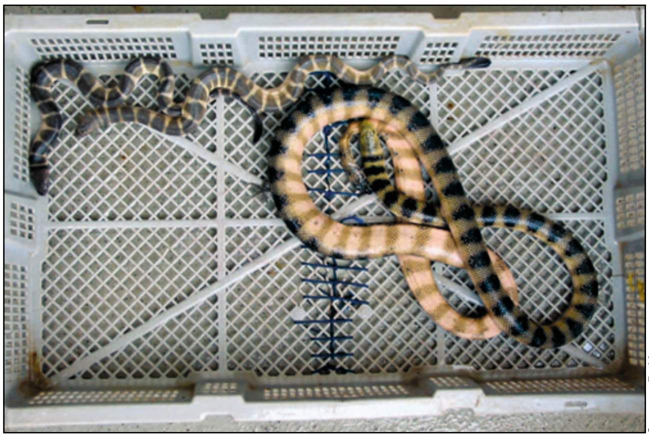

Plate 3.3 Sea snakes

No seagrass or corals were identified along the proposed route outside of Caution Bay, however both corals and seagrass do occur within Caution Bay. This environment was subject to detailed surveys by Coffey Natural Systems (2008a), the results of which are provided as an Appendix to the PNG LNG EIS.

3.1.1 Infauna

This section summarises the results of the infauna sampling carried out along the proposed offshore pipeline route (see Section 1.3.1). Raw data is summarised in Table 3.1 and provided in Annex B.

Infauna[6] sampling was carried out at 23 separate sites during the marine pipeline survey (see Figure 1.2). A total of 488 animals were collected, resulting in the identification of 137 species. The most common group of animals collected were polychaete worms, with 193 animals from 56 species being identified. Other identified groups include other annelids (e.g., oligochaetes) crustaceans, molluscs, echinoderms, poriferans, cnidarians, bony fish and nemertean worms.

Analysis of results showed no strong geographical patterns. Two sites shallower than 20 m were sampled, both of which are located between the mouth of the Omati River and the Kumul Marine Terminal (see Figure 1.2). Infauna present in these shallower waters along the proposed route are not significantly different from those in deeper sites further along the pipeline route. This is not unexpected, as sediments collected along the route were similar (very fine, comprising of silts and clays). In summary, no great differences were observed from the data set, which suggests that there are no unusual habitats and that the substrate type is fairly uniform along the pipeline route.

3.2 Marine Fauna

3.2.1 Fish and Crustaceans

Many species of fish and crustaceans occur in the Gulf of Papua and are described in Section 4.2.2. This information was obtained from trawl surveys of the prawn fishing grounds carried out by NFA[7] in 2004 and 2005 to investigate the current status of prawn stocks and the Gulf of Papua Fishery (NFA, pers. com., 2005).

3.2.2 Marine Reptiles

Marine reptiles represented in the Gulf of Papua are crocodiles, sea snakes and turtles.

Two species of crocodile inhabit the estuaries of the Gulf of Papua; the freshwater or New Guinea crocodile (*Crocodilus novaeguineae*), and the estuarine or saltwater crocodile (*Crocodilus porosus*) (Pernetta & Burgin, 1983; Genolagani & Wilmot, 1988). Typically, *C. porosus* is more abundant in estuarine waters and *C. novaeguineae* inland.

There are 23 species of sea snake known to inhabit PNG waters. While most sea snake species occupy nearshore waters and estuaries, some species inhabit the open sea and can dive to depths in excess of 100 m (Williams et al., 2004). Sea snakes of the Gulf of Papua are most commonly seen amongst the catches in the prawn trawlers where they sometimes appear in large numbers (Plate 3.3).

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[6] Aquatic animals that live within the bottom substratum rather than on its surface.
[7] Part of a program funded by the Australian Centre for International Agricultural Research.

Table 3.1 Summary of infauna collected along proposed offshore pipeline route

Classification*	No. of Species	Site																								Total No. of Animals
		1	**3**	**5**	**7**	**10**	**12**	**14**	**17**	**18**	**20**	**23**	**26**	**27**	**28**	**30**	**32**	**34**	**36**	**37**	**38**	**40**	**41**	**42**	**44**	
Porifera	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Cnidaria Hydrozoa	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	**4**
Cnidaria Anthozoa	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
Nemertean	4	2	1	2	0	0	1	0	0	1	0	0	0	2	1	1	0	0	0	0	0	1	0	0	2	**14**
Annelid Oligochaete	1	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Annelid Polychaete	56	22	18	1	0	0	9	2	12	1	0	18	1	10	9	4	17	1	11	0	3	9	10	22	13	**193**
Crustacea Ostracoda	11	0	4	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	4	0	0	0	0	4	5	**21**
Crustacea Tanaidacea	15	0	0	0	0	0	2	0	1	0	0	1	0	3	1	2	2	1	5	0	0	1	2	13	8	**42**
Crustacea Isopoda	4	1	0	2	1	0	1	0	1	0	0	0	0	2	0	0	2	0	1	0	0	0	0	1	2	**14**
Crustacea Amphopoda	14	3	9	8	2	0	4	0	2	0	0	4	0	18	1	9	3	0	12	0	0	2	2	18	9	**106**
Crustacea Decapoda	9	1	1	0	1	0	0	0	3	0	0	0	0	6	1	0	3	0	1	0	0	2	2	7	2	**30**
Phoronida	2	0	0	1	0	0	1	0	1	0	0	0	0	0	2	2	0	0	3	0	0	1	0	0	1	**12**
Mollusca Bivalvia	4	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	**11**
Mollusca Gastropoda	4	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**5**
Echinodermata	3	0	2	0	0	0	0	1	1	0	0	0	0	6	0	1	1	1	5	0	1	0	1	3	2	**25**
Osteichthyes	4	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	**6**
Total	**137**	**30**	**47**	**14**	**5**	**1**	**19**	**3**	**24**	**2**	**0**	**24**	**1**	**48**	**15**	**19**	**29**	**4**	**48**	**1**	**5**	**17**	**17**	**70**	**45**	**488**

*Classifications: Porifera = Phylum, Cnidaria = Phylum, Hydrozoa = Class, Anthozoa = Class, Nemertean = Phylum, Annelida = Phylum, Oligochaete = Class, Polychaeta = Class, Crustacea = Subphylum, Ostracoda = Class, Tanaidacea = Order, Isopoda = Order, Amphopoda = Order, Decapoda = Order, Phoronida = Phylum, Mollusca = Phylum, Bivalvia = Class, Gastropoda = Class, Echinodermata = Phylum, Osteichthyes = Class.

Six species of sea turtle occur within PNG waters, specifically the green turtle (*Chelonia mydas),* hawksbill turtle (*Eretmochelys imbricata),* leatherback turtle (*Dermochelys coriacea)*, olive ridley turtle *(Lepidochelys olivacea),* loggerhead turtle *(Caretta caretta)* and flatback turtle *(Natator depressus).* All of the world's sea turtles are listed by the International Union for the Conservation of Nature (IUCN), the World Conservation Union's Red Data Book of Threatened Species (IUCN, 2007). In the Gulf of Papua, there are no known nesting beaches for any species. Turtles are often caught in prawn trawl nets in the Gulf of Papua, including the olive Ridley (Plate 3.4) and green turtle (Plate 3.5).

3.2.3 Marine Mammals

Dugongs (*Dugong dugon*) occur along coastal areas of PNG, mainly to the west of the Fly River Delta away from the proposed offshore pipeline route, where less turbid waters allow the development of seagrass beds upon which they feed. They are exclusively marine and grow to approximately 3 m in length and up to 450 kg and live for around 70 years. The dugong is listed as vulnerable in the IUCN World Conservation Union's Red Data Book of Threatened Species and it is therefore considered to be at high risk of extinction in the wild (IUCN, 2000). It is also a protected under the *Fauna Protection Control Act PNG 1976*.

Whales are not often seen in the Gulf of Papua but species that may occasionally be present in the area include the Bryde's whale (*Balaeonoptera edeni*), sperm whale (*Physeter catodon*), minke whale (*Balaenoptera acutorostrata*) and humpback whale (*Megaptera novaeangliae*). The sperm whale and humpback whale are both listed as threatened and the minke whale is listed as lower risk 'near threatened' by the IUCN (Cetacean Specialist Group, 1996a, b, c).

Various dolphin species are present in the gulf, including the bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), the Indo-Pacific humpback dolphin (*Sousa chinensis*) (Plate 3.6) and the Irrawaddy dolphin (*Orcaella brevirostris*). Many of the species of dolphins are frequently observed in inshore waters near prawn trawlers, attracted to fish by-catch discarded overboard. During the marine pipeline survey, several dolphins, including a pod of 12 long beaked bottlenosed dolphins (*Tursiops aduncus*) were observed from the vessel (Plate 3.7).

Irrawaddy dolphins (*Orcaella brevirostris*) are a rare and poorly known species but surveys conducted in 1999 have reported sighting individuals from the Kikori River (Namo, 2003). They inhabit turbid waters and travel up large river systems but generally stay within 5 km of the coast. The newly recognised the Snubfin Dolphin, *Ocraella heinsohni*, is also found in the southern parts of Papua New Guinea (Beasely et al., 2005).


Source: D. Gwyther

Plate 3.4 Olive ridley turtle in prawn trawl catch


Source: D. Gwyther

Plate 3.5 Green turtle in prawn trawl catch


Source: D. Gwyther

Plate 3.6 Indo–Pacific hump backed dolphin observed from a prawn trawler


Source: N. Goldsmith

Plate 3.7 Dolphins observed during the marine pipeline survey

4. MARINE FISHERIES

4.1 Overview

The development and management of the marine biological resources of PNG falls under the jurisdiction of the NFA, a non-commercial statutory body that was established in 1995. NFA works under the *Fisheries Management Act 1998* and related fisheries regulations.

The main commercial fishery in the Gulf of Papua is the Gulf of Papua Prawn Fishery. This fishery operates in several areas within the gulf, and the proposed offshore pipeline route traverses the trawl grounds. There is also a range of other fisheries (small-scale commercial and subsistence) exploiting mud crabs, lobsters, barramundi, sharks, mackerel, skipjack and yellowfin tuna in the Gulf of Papua, however these fisheries operate mainly in coastal areas that are not traversed by the proposed offshore pipeline.

4.2 Gulf of Papua Prawn Fishery

Prawn trawling has been operating continuously in the Gulf of Papua since the 1970s. The fishery is currently managed in accordance with the Gulf of Papua Prawn Fishery Management Plan, developed by NFA in 1998.

The fishing grounds extend from the Fly River mouth in the west to the village of Iokea in the east, close to the border between Gulf Province and Central Province. The productive grounds extend along the coast, generally located between the 10 and 40 m depth contours.

The Gulf of Papua prawn fishery is one of the most valuable fisheries in PNG. Current catches of between 400 and 650 tonnes of banana prawns and 160 tonnes of black tiger prawns per year, brining an annual economic return of about K15 million (ACIAR, 2006). Prawn catch data is outlined in Table 4.1.

Table 4.1 Prawn fishing effort and catch in Gulf of Papua

Year	Number of Trawlers	Total Hours Fished	Total Weight (Mt)
2004	15	327,480	1,058.61
2005	12	107,075	1,046.85
2006*	6	38,830	395.50
2007*	3	22,290	182.21

* Data for 2006 and 2007 is incomplete as companies have yet to submit all catch reports. Values are likely to be higher, although lower than 2004 and 2005.

Source: Philip and Uakuru. pers. com., 2008.

A variety of prawn species are targeted in the Gulf of Papua. Table 4.2 shows the species and total weights of prawns caught in the Gulf of Papua during the recruitment surveys undertaken by NFA from 2004 to 2006 (Figure 4.1).

Table 4.2 Prawn species and total weights from survey

Scientific Name	Common Name	Total Weight (tonnes)		
		2004	2005	2006
Caridacea	Mixed carids		1.53	10.2
Parapenaeopsissculptilis	Flower prawn	129.8	133.4	303.6
Atypopeneaus formosus	Orange prawn	5.0	9.0	
Atypopeneaus bicornis	White shrimp		3.1	
Metapeneus eboracensis	Green prawn		0.94	
Metapeneus demani	Green endeavour	95.1	202.3	231.1
Metapeneus endeavouri	Blue endeavour		0.4	
Metapeneus ensis	Red endeavour	109.2	29.8	92.9
Peneaus indicus	Indian banana	43.3	8.4	18.7
Peneaus japonicus	Japanese tiger	7.0	6.0	3.8
Peneaus merguiensis	White banana	733.6	480.7	425.7
Peneaus monodon	Giant tiger/black tiger	169.9	102.1	104.8
Peneaus semisulatus	Grooved tiger	6.7	0.5	3.4
Heterocarpus sp.	Pink carid	6.1	79.6	
Metapenaeopsis wellsi	Coral prawn	8.7		12.6
Total		**1,314.0**	**1,057.7**	**1,206.8**

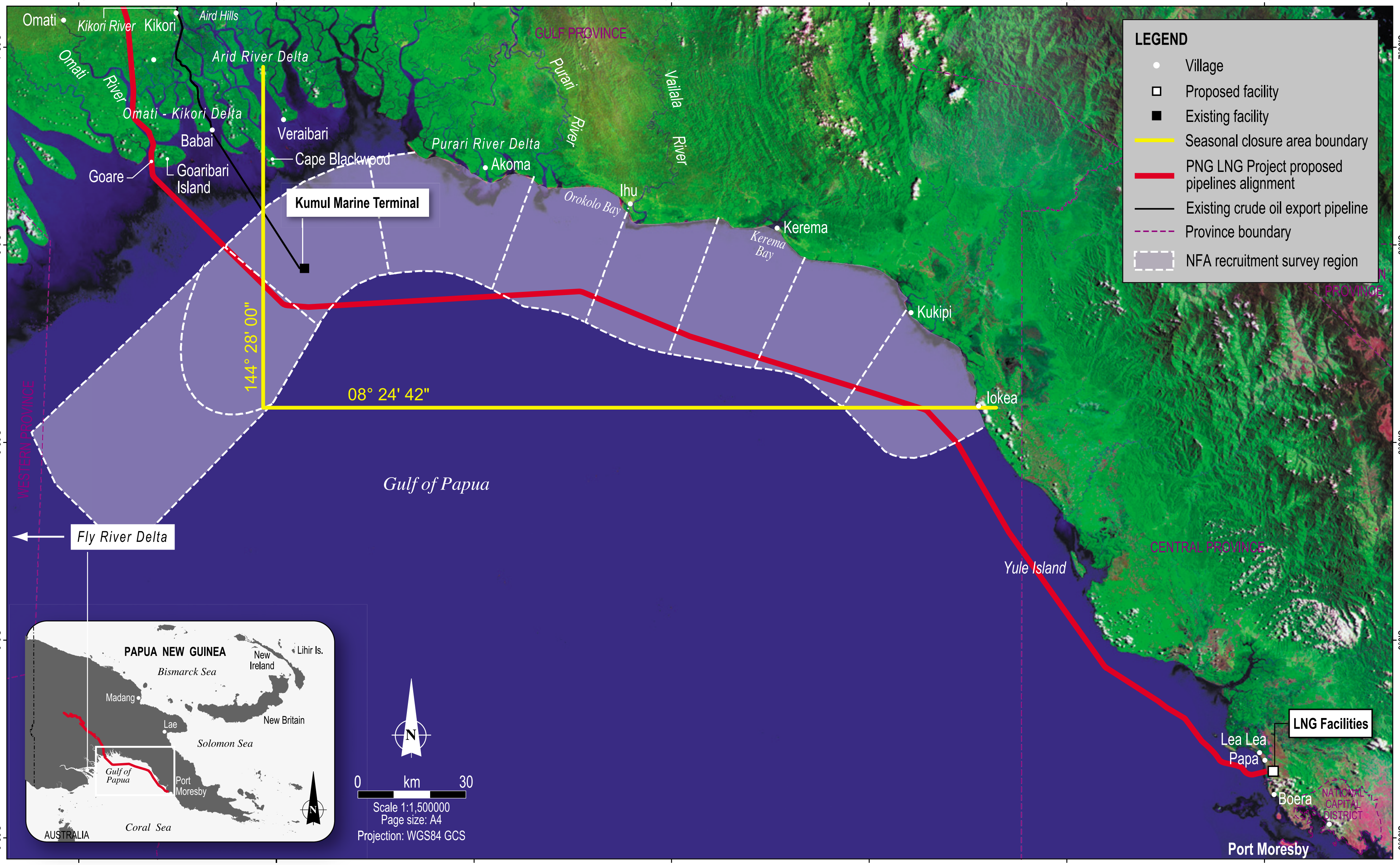
Source: Koren, 2004a, 2005, 2006.

Over the three-year survey, the species with the highest percentage composition (by number and weight) were *P. sculptilis, P. merguiensis, P. monodon and M. demani.* These are the primary commercial fisheries species. Comparing the three surveys, there was an increase of recruits for the two banana prawn species (*P. merguiensis* and *P. indicus*) of 16% from the 2004 to 2005 survey but an 18% reduction in recruits in the 2006 survey (Koren, 2006).

The new recruits migrate eastwards from the nursery areas (Aird River Delta, and the Kikori, Purari and Vailala rivers) (see Figure 4.1) toward Kerema Bay. During December to March each year, the recruits grow, reaching legal fishing size (greater than 28 mm carapace length) in around March to April, when they move to deeper waters (approximately 12 m deep) where commercial fishing occurs (Koren, 2006).

These sensitive nursery areas have been protected by an area seasonal closure since 1995. The closure is effective from 1 December to 31 March for the trawl grounds from Iokea to Cape Blackwood. Trawling may take place outside these areas (south of latitude 8^{o} 24' 42' and west of longitude 144^{o} 28' 00') (see Figure 4.1).

There are 15 vessels currently licensed to trawl for prawns. These must not exceed 30 m overall length (most are around 24 m in length and 150 gross tonnes) and have main engines not more than 550 horsepower. The vessels are mostly twin-rigged or quad-rigged with otter board



Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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Gulf of Papua Prawn Fishery recruitment survey areas and seasonal closure boundaries

Figure No: 4.1

dimensions approximately 1.8 m by 1.2 m and combined footrope lengths of around 50 to 60 m (Plate 4.1). All processing and freezing is done on-board after each haul. There are no harbour facilities adjacent to the gulf fishing grounds and the vessels operate from Port Moresby, about 24 hours' steam away, and remain at sea for periods of four to five weeks. Fishing takes place on a 24-hour basis and each trawl shot is on average about 4 hours, towed at speeds of around 3 knots. The bottom types at the trawling grounds consist of consolidated mud or silt.

4.2.1 Distribution of Fishing Effort

All of the Gulf of Papua prawn trawlers are fitted with vessel monitoring systems, whereby the Global Positioning System coordinates of the vessels are recorded each day by NFA. This system was introduced in 2000, and Figures 4.2, 4.3 and 4.4 show all records of daily vessel positions for 2005, 2006 and 2007, respectively. These figures clearly show that the main fishing grounds are centred around Kerema Bay. The other concentrations of trawling effort are:

- Orokolo Bay and south of the Purari River Delta.
- To the south of Cape Blackwood and the Omati River mouth.
- A small area east of the north arm of the Fly River Delta.

The gap in the trawl grounds offshore of Cape Blackwood indicates the exclusion area around the Kumul Marine Terminal. A 15-km–length of the proposed pipeline route south of the Kumul Marine Terminal is regularly trawled (see Figures 4.2, 4.3 and 4.4). Routes used by fishing vessels transiting between trawling grounds and Port Moresby are shown in Figures 4.2, 4.3 and 4.4 and these figures show that the proposed pipeline route falls within parts of these routes. Currently, the commercial vessels are prohibited from fishing within 3 nautical miles (nm) of the coast. Despite this restriction, however, many trawlers still operate in this area (ACIAR, 2006).

4.2.2 By-catch and Other Species

As with most prawn trawl fisheries, commercially marketable prawns generally comprise less than 10% of the catch, with the remaining by-catch being both too substantial in volume and too low in value to retain. Most by-catch includes numerous species of fish such as pony fish, hairtails, anchovies, clupeids, jewfish, goatfish, Bombay duck and invertebrates such as squid, crabs and mantis shrimps. Various studies have examined potential use of trash fish for retail or sale as crocodile feed (Anon, 1979), but handling the volume has prevented successful implementation. Crew usually retain larger edible species, such as snapper. When conditions are calm, local canoes often pull alongside trawlers to exchange fruit and sago for fish by-catch (Plate 4.2). Occasionally, very large sharks, sawsharks and rays are also amongst the catch (Plates 4.3 and 4.4). Several species of sea snakes (see Plate 3.3) are numerous and turtles (green, olive ridley and flatback) are occasionally caught in the nets (see Spring, 1979; Plates 3.4 and 3.5). Under the Gulf of Papua Prawn Fishery Management Plan, all live turtles must be returned and the removing of fins from sharks is prohibited. Turtle exclusion devices have been trialled in this fishery, however, are not currently in use (Mobiha, pers. com., 2008).

Source: D. Gwyther

Plate 4.1 Gulf of Papua prawn fishery trawler in Port Moresby

Source: D. Gwyther

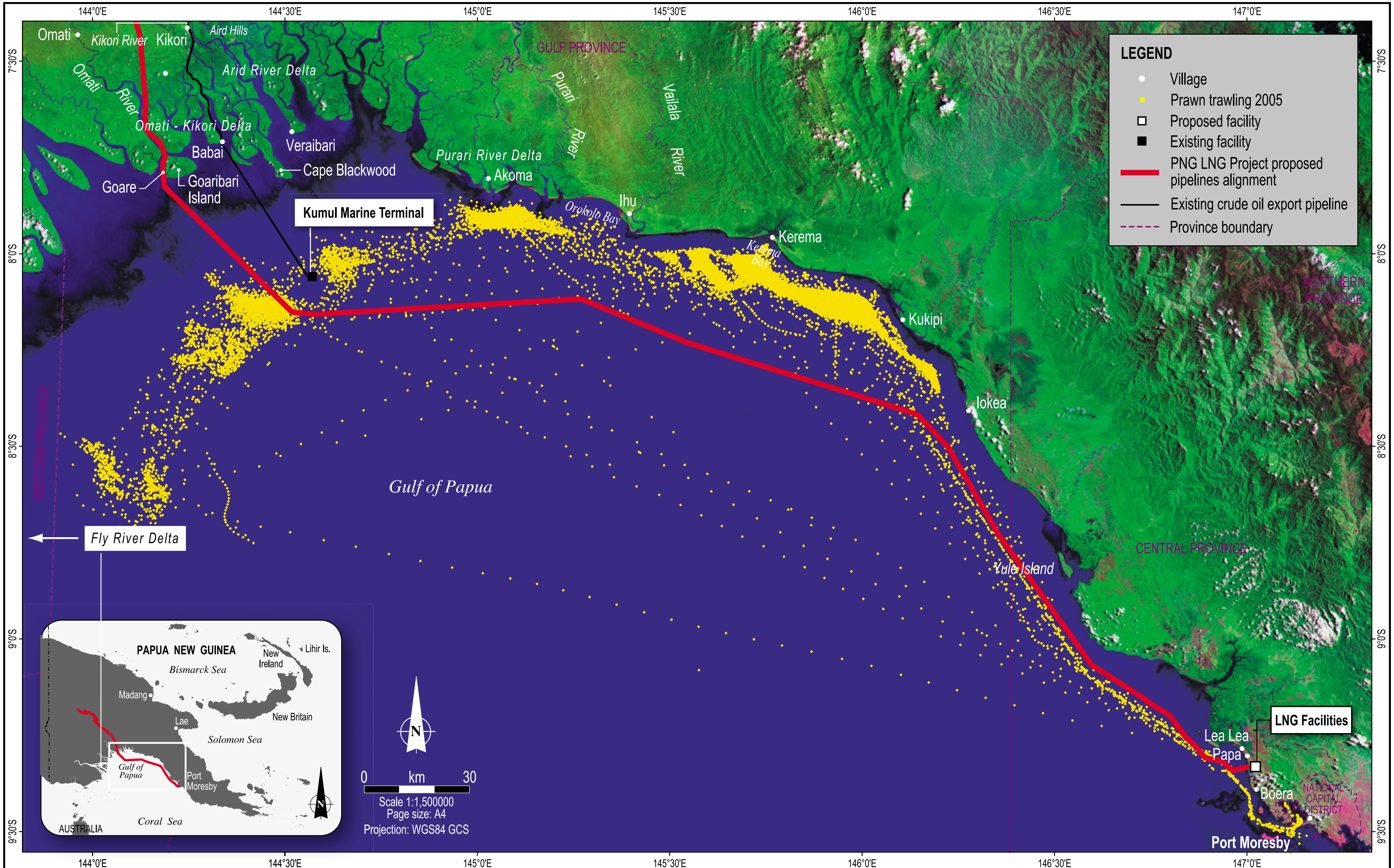
Plate 4.2 Canoes getting trash fish from a prawn trawler

Source: B. Kare

Plate 4.3 Shark in prawn trawl catch

Source: B. Kare

Plate 4.4 Ray in prawn trawl catch



Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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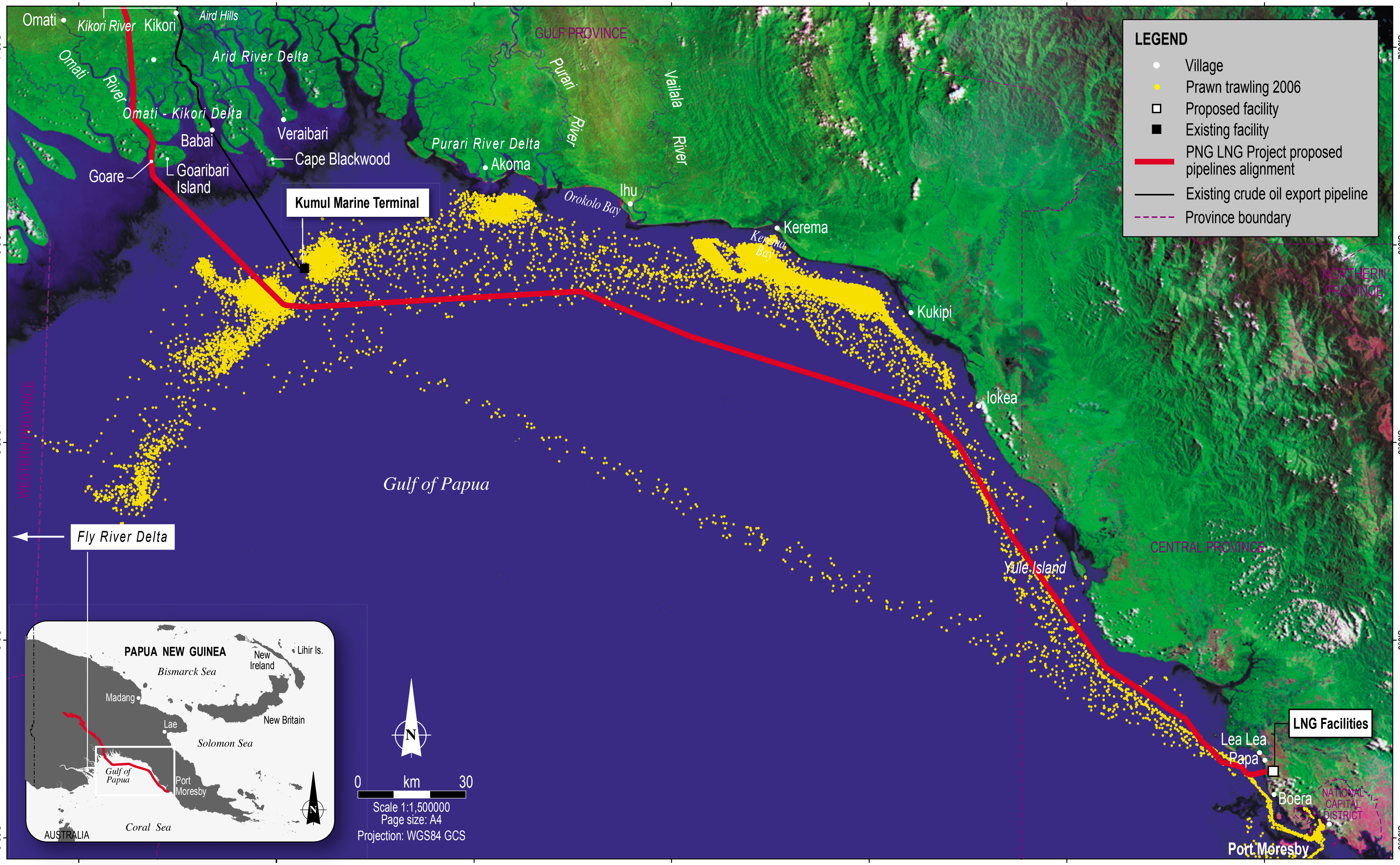
Gulf of Papua Prawn Fishery vessel monitoring data – 2005

Figure No: 4.2



Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008. Some vessel tracks in the centre of the Gulf of Papua appear anomalous compared to the previous (2005) and following (2007) seasons and are not likely to be prawn trawling given the depths.

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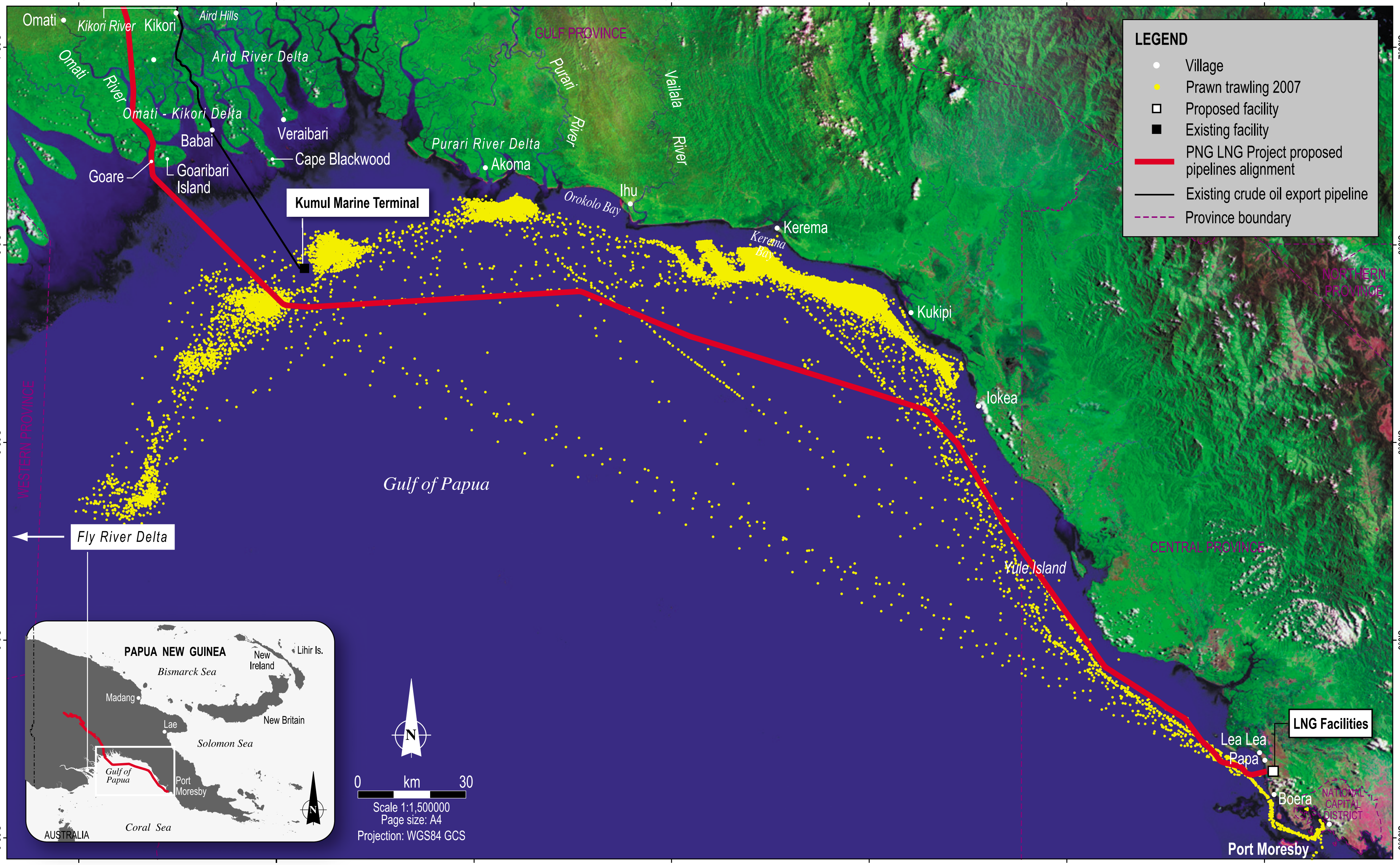
Gulf of Papua Prawn Fishery vessel monitoring data – 2006

Figure No: **4.3**



Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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Gulf of Papua Prawn Fishery vessel monitoring data – 2007

Figure No: 4.4

4.2.3 Future of the Gulf of Papua Prawn Fishery

Catch statistics have indicated that the existing rate of harvesting was not economically or biologically sustainable and it has been recommended that additional management practices, such as reducing the maximum catch per year, adjusting seasonal opening times and reducing the number of fishing licences should be implemented to ensure the viability of the industry (ACIAR, 2006). However, recent research on the status of prawn stocks in the Gulf of Papua (commissioned by CSIRO Marine Research, Australia) recommended that fishing operators be allowed to access these more productive inland waters (either during restricted times or with prior access agreements) as this would allow increased fishing without further impacting the productivity or economic viability of the industry (ACIAR, 2006). A review of the Gulf of Papua Prawn Fishery Management Plan is being undertaken by NFA and the revised plan includes changing the 3 nm exclusion zone to a 2 nm exclusion zone, with any prawn trawling occurring within 2 to 3 nm from shore requiring prior consultation with traditional owners (Mobiha, pers. com., 2008).

NFA has allocated up to 10 licences for a small-scale prawn fishery in the inshore waters under the current Gulf of Papua Fishery Management Plan, but these are not active. This is likely due to the lack of local harbour facilities and the long distance to markets.

Recent rises in fuel costs and declines in prawn prices have significantly affected the economic viability of the prawn industry (ACIAR, 2006) and there has been an approximate 40% reduction in fishing effort, with the number of vessels operating in the Gulf Prawn Fishery falling from 15 to approximately nine (Mobiha, pers. com., 2008).

4.3 Other Gulf Fisheries

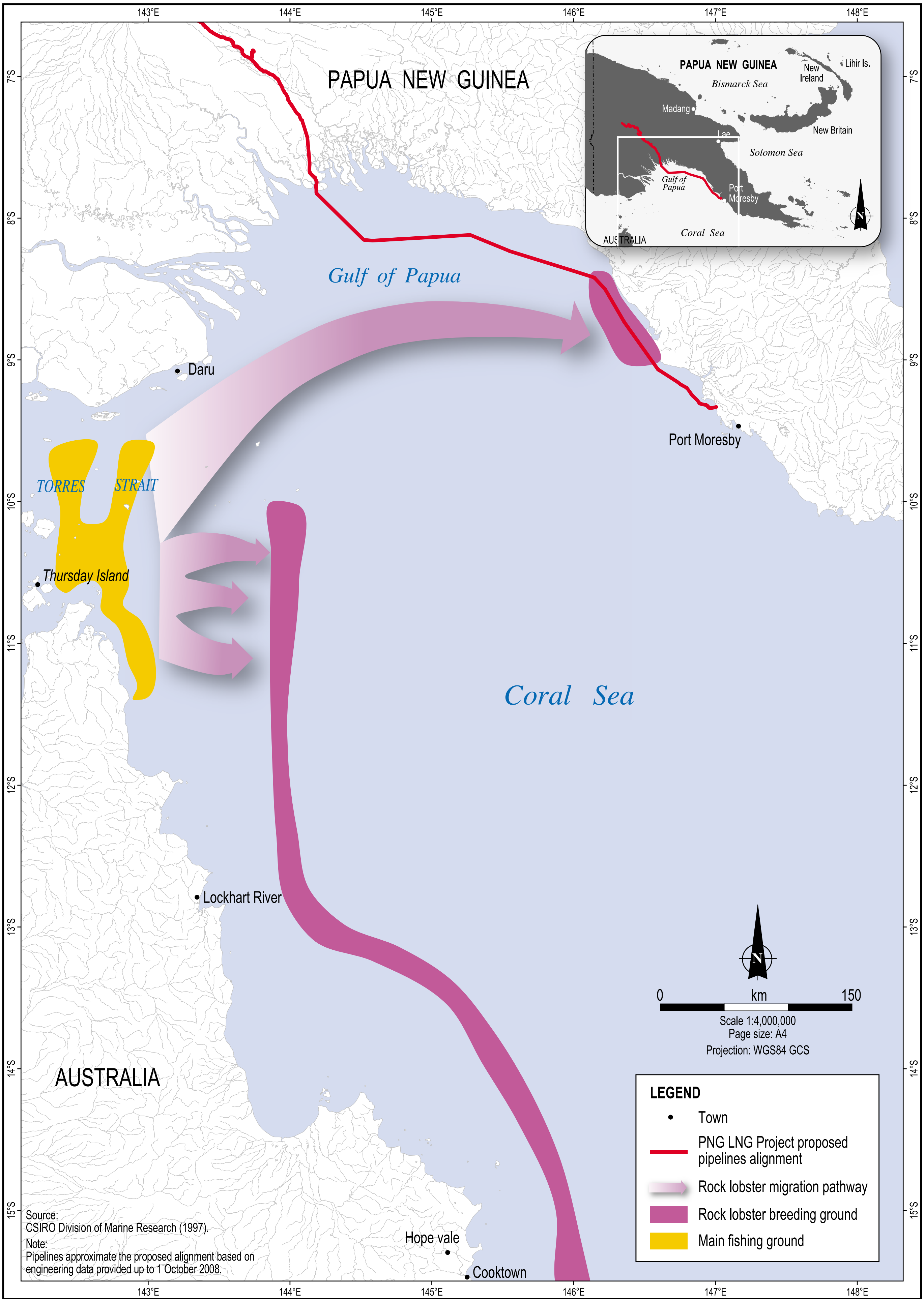
The variety and abundance of fish, mud crab, prawn and lobster resources all along the Gulf of Papua coast support fishing for subsistence sale to local markets and other small-scale localised commercial ventures. Subsistence fishing involves the use of a variety of pots, traps and gill nets. V-shaped scoop nets are commonly used along the beaches targeting fish and sub-adult prawns as they migrate from the inshore nursery areas to the offshore grounds.

4.3.1 Barramundi

The main species fished for subsistence sale is barramundi (*Lates calcarifer*). Seasonal gill net fishing takes advantage of the relatively predictable spawning movements along a 150-km–long narrow coastal strip on the south coast of PNG and west of Daru, before the barramundi return to their inland river habitats (Kare, 1995). Other high-value species such as threadfin (*Polynemidae*), jewfish (*Sciaenidae*) and catfish (*Ariidae*) are also targeted.

4.3.2 Tropical Rock Lobster

Tropical rock lobsters (*Panulirus ornatus*) annually migrate from reefs in northern Queensland and Torres Strait across the Gulf of Papua to the reefs of Yule Island in the eastern Gulf of Papua, northwest of Port Moresby and further east along the South Papuan Coast where they spawn (Figure 4.5). The migration is related to spawning and occurs during August to December each year. The migration path through the Gulf of Papua is coincident with the deeper part of the prawn trawl grounds, mostly between 40 and 80 m. There is no evidence of a return migration by adults (Moore & MacFarlane, 1984). While Figure 4.5 shows the pipeline crossing a wide breeding ground to the northwest of Port Moresby, the spawning actually takes place on the coastal reefs inshore of the pipeline route.



PNG LNG	Date: 19.09.2008 MXD: PNG_LNG_Project_GIS.mxd File Name: 1284_07_F04.05_GIS_HB	Esso Highlands Limited PNG LNG Project	Tropical rock lobster migration paths through the Gulf of Papua	Figure No: 4.5

Rock lobsters are fished at both ends of the annual migratory route and in the past, were fished heavily by the prawn trawlers. To preserve the breeding population, a ban was placed on trawling for lobsters in both Australia and Papua New Guinea in 1984. Expansion of the diver-based industry is reserved for traditional inhabitants, with limited entry for non-traditional inhabitants (NFA, 2002). The prawn trawlers ceased receiving allowable quotas of migrating aggregations of rock lobsters because of impacts to the local reef-based fisheries. Trawling has been banned since 1984 and although some trawling has been done in the Gulf of Papua over the last few years (Ye et al., 2006). The results of modelling of lobsters stocks show that a reopening of trawling would reduce stocks and cause loss of catch to fishery (Ye et al., 2006).

4.4 Fishing In the Omati–Kikori Delta

This section is based on a field survey undertaken by Coffey Natural Systems (2008b), the findings of which are provided as an Appendix to the PNG LNG Project EIS and summarised below.

The primary fishing methods used in the Kikori and Omati rivers are set gill nets, hand lines, cast nets and spears. The species caught include barramundi, threadfin salmon, catfish, black bass, bream, nursery fish, pony fish, prawn, macrobrachium, mud crab and crocodile. Fishing activities are undertaken using dinghies with outboard motors and canoes with paddles and/or outboard motors. These vessels are also used for transportation.

Fishing is mainly a subsistence activity, and essential as a source of daily food for the people of the area. While surplus catch is sold to markets and logging camps, this is opportunistic and fishing as a commercial-scale activity (i.e., for selling to fish processing plants) has declined, with fishermen and women seeking other sources of income.

5. MARINE TRAFFIC

This section describes the marine traffic operating offshore within the Gulf of Papua. Marine traffic in Caution Bay and the Omati–Kikori Delta and are described in two reports by Coffey Natural Systems (2008a, b), both of which are Appendices to the PNG LNG Project EIS.

This chapter is based on discussions with Mr Karme, Mr Kabilu and Mr Tavul from PNG Ports Corporation Ltd[8] (PNG Ports), a port authority wholly owned by the State of PNG and responsible for 21 declared ports throughout PNG, including the Port of Port Moresby and the Port of Daru (Figure 5.1). Shipping register records (PNG Ports, 2007) and the PNG Harbours 2004 Annual Report (PNG Harbours, 2004) were used to provide data on the numbers and types of vessels berthing at the Port of Port Moresby and the Port of Daru. Records from these ports give an indication of the likely vessel types and frequency of occurrence along the proposed pipeline route.

There are no defined shipping channels along the proposed offshore pipeline route.

5.1 Port of Port Moresby

Port of Port Moresby is a medium-sized seaport located in Fairfax Harbour on the eastern side of the Gulf of Papua (see Figure 5.1), where annually, over 1,400 overseas and coastal vessels berth. A summary of the number and types of vessels is provided in Table 5.1.

Table 5.1 Summary of vessels that berthed at the Port of Port Moresby during 2005 and 2006

	Type of Vessel	2005	2006
Overseas	Container	58	68
	General cargo	106	91
	Tanker	79	89
	Ro-Ro	14	13
	Cruise	5	10
	Log ship	94	77
	Other	155	138
Total		*511*	*486*
Coastal	General cargo	221	220
	Tanker	-	-
	Barge	105	132
	Passenger	25	57
	Other	557	519
Total		*908*	*928*
Overall Total		**1,422**	**1,414**

Source: Adapted from PNG Ports, 2007.

[8] Formerly PNG Harbours Limited.

Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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Key ports within the Gulf of Papua

Figure No: 5.1

Overseas vessels entering the Port are generally from Australia, China, Indonesia, Malaysia and Hawaii (PNG Ports, 2007). Coastal vessels travel to and from the Port from locations within the Gulf of Papua, including Daru, the Kumul Marine Terminal and Kiunga, and other areas in PNG, such as Lihir, Lae, Kimbe and Rabaul.

Small bulk carriers transport Ok Tedi Mine copper concentrate from the Fly River to the Port of Port Moresby between May and September (Kabilu, pers. com., 2007). Log carriers deliver timber from the Paia Inlet (just east of the Omati River) to the Port of Port Moresby (Kabilu, pers. com., 2007). These shipping routes are likely to be traversed by the proposed offshore pipeline.

5.2 Other Gulf of Papua Ports

Other ports within the Gulf of Papua include the Port of Daru, Napa Napa Oil Refinery and Kumul Marine Terminal (see Figure 5.1).

The Port of Daru is a small jetty port located on the western side of the Gulf of Papua and vessels using this port typically include logging transport ships and fishing vessels (PNG Harbours, 2004):

The port at the Napa Napa Oil Refinery, owned by InterOil, is located near Port Moresby (within Fairfax Harbour), and handles the export of oil and minerals, such as copper concentrate from the Ok Tedi mine (Kabilu, pers. com., 2007).

The Kumul Marine Terminal is situated near the Omati–Kikori Delta at the end of an oil pipeline and is used to export oil associated with Oil Search's Kutubu Petroleum Development Project. The terminal receives oil tankers and supply vessels. The proposed offshore pipeline has been routed to avoid the Kumul Marine Terminal and its associated anchoring zone.

6. ISSUES AND ASSESSMENT OF SIGNIFICANCE

This chapter describes the potential issues associated with the construction and operation of the offshore section of the LNG Project Gas Pipeline in relation to the marine biological and social environment. The chapter also ranks these impacts in terms of their significance.

6.1 Approach to Impact Assessment

The significance of the potential impacts associated with the construction and operation of the offshore section of the LNG Project Gas Pipeline were derived from the analysis of:

- The amount and type of change, including the timing, scale, size and duration of the impact (magnitude).
- The sensitivity of the environment to change, including its capacity to accommodate the kinds of changes the project may bring about (sensitivity of resource/receptor).

6.1.1 Magnitude of Impact

The magnitude of an impact reflects:

- The intensity or severity of the impact.
- How long the impact will last.
- Over what spatial extent will the impact be felt.

Using the above criteria, categories and definitions of magnitude were determined as shown in Table 6.1 in order to determine an overall impact assessment. In the following section the impact assessment is made (in most cases) prior to the implementation of any mitigations.

Table 6.1 Magnitude of impact

Category	Description
Very High	Effect likely to have large impact on population, community or ecosystem survival and health, possibly even leading to extinction or system collapse. Impact is widespread, affecting more than 10% of a regional population. Recovery, if possible, is likely to take more than 25 years.
High	Effect likely to have severe negative impact on population, community or ecosystem survival or health. Impact is regional, affecting up to 10% of a regional population. Recovery, if possible, is likely to take up to 25 years.
Medium	Effect will be detectable but not severe; populations or the areal extent of communities may be reduced but unlikely to lead to major changes to population, community or ecosystem survival or health. Impact is local, generally occurring within 10 km of impact site. Recovery is likely to take up to 7 years.
Low	Effect may be detectable but is small and highly unlikely to have any material impact. Impact is limited, affects immediate surrounds of impact area and extends for up to 2 km radius. Recovery is short term up to 3 years.
Minimal	Effect unlikely to be detectable.
Positive (P)	Change is likely to benefit the population, community or ecosystem.

6.1.2 Sensitivity of Resource/Receptor

The sensitivity of the environmental resource/receptor will reflect:

- Its formal status, whether by statutory or attributed conservation status.
- Its vulnerability to material damage or loss by the impact in question.
- Its iconic or symbolic importance to cultural value systems.

The sensitivity of the resource/receptor was analysed from the baseline information and classified into categories based on Table 6.2.

Table 6.2 Sensitivity of resource/receptor

Category	Description
Very High	A population of an ecologically or socially important species on an international level, or a site or habitat supporting such a species. A rare, threatened or vulnerable habitat or species and/or a breeding ground or feeding area that is critical to the survival of such species. Resource that provides the sole source of food or income for a local population.
High	A nationally designated site. A sustainable area of priority habitat. A population of an ecologically or socially important species on a national level, or a site or habitat supporting such a species. Site supports 1% or more of national population. Resource that provides a large portion of food or income for a local population.
Medium	A population of an ecologically or socially important species on a regional level, or a site or habitat supporting such a species. Site supports 1% or more of regional population. Resource that provides a medium portion of food or income for a local population.
Low	Sites, populations or resources that enrich the local area. Resource that provides a small portion of food or income for a local population.
Minimal	No ecological or social value or sensitivity.

6.1.3 Assessment of Significance

A significance matrix (Table 6.3) was used to combine the information about the sensitivity of the resource/receptor with the information previously complied regarding the magnitude of the impacts.

Table 6.3 Matrix of significance

Magnitude of Impact	Sensitivity of Resource/Receptor				
	Very High	High	Medium	Low	Minimal
Very High	Major	Major	Major	Moderate	Minimal
High	Major	Moderate	Moderate	Minor	Minimal
Medium	Moderate	Moderate	Minor	Minor	Minimal
Low	Moderate	Minor	Minor	Minor	Minimal
Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Positive	Positive	Positive	Positive	Positive	Positive

6.2 Issues and Impact Assessment

The issues that the project needs to address are:

- Increased suspended sediment and sedimentation rates.
- Disposal of hydrotest water.
- Interaction of vessels with marine mammals.
- Underwater noise.
- Direct disturbance to seafloor habitat.
- Waste discharge from vessels.
- Spillage of hazardous substances.
- Interaction with commercial fisheries.
- Interaction with subsistence fisheries and small craft.
- Interference with tropical rock lobster migration.
- Interference with shipping.
- Entanglement of anchors or fishing gear with pipeline.
- Quarantine.

These are discussed in detail below.

6.2.1 Increased Suspended Sediment and Sedimentation Rates

Issue

Installation of the offshore pipeline, including pipelaying, the placement and retrieval of anchors (if an anchored laybarge is used[9]) and trenching will resuspend bottom sediments and increase turbidity downcurrent of the areas of disturbance and increase sedimentation rates. In turn, this decreases light penetration and can smother marine biota. For economic reasons, the pipeline has been routed to minimise the amount of trenching required.

Impact Assessment

Magnitude of Impact

The extent of detectable increases in suspended sediment and sedimentation rates is expected to be within the same general vicinity and less than 2 km from the impact source. Being from the same location, the disturbed sediments will be of the same particle sizes as those that naturally settle in the area. The duration of the impact will be limited to when the pipelaying and trenching activities are being undertaken.

Pipelaying is expected to progress at a rate of 1 to 3 km per day. Trenching (for the required section of the offshore pipeline) is scheduled to take approximately one year.

For reasons discussed above, the magnitude of impact is considered to be LOW.

Sensitivity of Resource/Receptor

The majority of the route from the Omati River Landfall to the approaches to Caution Bay is not route-sensitive to the extent that the same environments are crossed and environmental (sedimentation) impacts will be the same regardless of any deviations from the proposed route centreline.

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[9] At the time of writing, the use of an anchored laybarge and a dynamically positioned laybarge were both being considered by the project. For the purposes of assessing impacts relating to increased levels of suspended sediment an anchored laybarge is used, as this type of vessel would cause greater increases in suspended sediment than a dynamically positioned laybarge.

At the Omati River end of the pipeline, the waters naturally have high levels of suspended sediment (see Section 2.5) and marine biota inhabiting this area are adapted to these conditions and unlikely to be impacted by short-term increased levels of suspended sediment. Further offshore, away from the influence of the Omati–Kikori Delta, the waters naturally have lower levels of suspended sediment however, as discussed in Section 3.1, seabeds are predominately silts and clay and it is unlikely that large communities of sensitive habitat, such as coral or seagrass, would be present along the offshore pipeline route from the Omati River Landfall until reaching the outskirts of Caution Bay.

As discussed in Section 4.4, the Omati River is utilised by local communities for subsistence fishing and this activity is important for their livelihood. However, as the Omati River naturally has high levels of suspended sediment, fisheries resources are unlikely to be impacted by pipelaying, anchor placement/retrieval or trenching activities.

The offshore pipeline route traverses prawn trawl grounds (see Figures 4.2, 4.3 and 4.4). There will be temporary and localised increases in suspended sediment during construction, however, the prawn grounds are naturally turbid from suspended sediment derived from the river input and remobilisation from wind and waves, and also from the action of prawn trawling equipment disturbing the seafloor.

For reasons discussed above, the sensitivity of resource/receptor is considered to be LOW.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

6.2.2 Disposal of Hydrotest Water

Issue

Hydrotesting is performed post-installation to confirm pipeline integrity and involves filling the entire offshore pipeline with water. The project is proposing to source seawater (approximately 220,000 m^3) from either the Omati River or Caution Bay for use in the hydrotesting process. Once testing is complete the hydrotest water will most likely be discharged into the Omati River.

Hydrotest water requires treatment with biocides and an oxygen scavenger to control sulfate-reducing bacteria, which can form hydrogen sulphide, and, in turn corrode the pipeline. Biocides and oxygen scavengers can be toxic to marine organisms. On disposal, organisms in the receiving water will be exposed to these chemicals.

Hydrotest water will also be a potential pathway for the introduction of non-native marine flora and fauna into the Omati River, if the hydrotest water is sourced from Caution Bay.

The project will obtain and meet conditions in the applicable Environment (Water Discharge) permits from the PNG Government prior to discharge of the hydrotest water.

Impact Assessment

Magnitude of Impact

The volume of hydrotest water to be discharged is approximately 220,000 m^3. The impact assessment below is based on discharge into the Omati River over a period of 7 to 10 days, corresponding to a discharge rate ranging from 15 to 22 m^3 per minute. The hydrotest water will contain residual quantities of an oxygen scavenger (e.g., Champion OS-2), originally dosed at 100 mg/L, and a biocide (e.g., Bactron B1150), originally dosed at 200 mg/L.

Materials Data Safety Sheet information states that Champion OS-2 is a reducing agent, biodegradable and slightly toxic to aquatic fauna. Bactron B1150 has a degradation rate of 64% in 28 days under aerobic conditions, which would be encountered in the Omati River. Table 6.4 gives the aquatic toxicity data (effect of concentration to 50% of test organisms after a particular time) for Bactron B1150.

Table 6.4 Aquatic toxicity data for Bactron B1150

Test	Organism	Test Type	Result
Algae	*Skeletonema costatum*	EC50 72 hr	1.2 mg/L
Crustacean	*Acartia tonsa*	EC50 48 hr	0.21 mg/L
Fish	*Sheepshead minnow*	EC50 90 hr	64 mg/L

Estimates of minimum flushing potential can be derived from tidal ranges in the Omati River, which are estimated to flush approximately 93 million m^3 of water[10] past the point of discharge over each six-hour tidal cycle. Therefore, it is estimated that hydrotest water discharged during each six hour tidal cycle would be diluted with Omati River water to 0.008% of the total water volume at the discharge point (assuming discharge is at the Omati River Landfall).

Concentrations of Champion OS-2 and Bactron B1150 in receiving waters six hours after discharge to the Omati River at the Omati River Landfall are estimated to be 0.008 and 0.017 mg/L respectively, indicating that concentrations will be well below exposure times and levels harmful to aquatic organisms.

In the hydrotest water, the dosage of biocidal and oxygen-removing treatment chemicals, together with the high pressure within the pipeline will create a hostile environment for organisms. The habitats at the source (i.e., Caution Bay) and discharge locations (i.e., Omati River) are dissimilar, and so the successful colonisation of species from open, clear saline waters in the vicinity of the turbid discharge location is unlikely.

For reasons discussed above, the magnitude of impact is considered to be LOW.

Sensitivity of Resource/Receptor

As discussed in Section 4.4, the Omati River is utilised by local communities for subsistence fishing and this activity is important for their livelihood, however, the Omati River is a dynamic environment and, as discussed above, is subject to a high volume of water turnover from both tidal flushing and freshwater inputs from upstream tributaries.

For reasons discussed above, the sensitivity of resource/receptor to once-off discharge of hydrotest water is considered to be LOW.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

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[10] Assumptions: Surface area of the Omati River upstream from the landfall location = 46.8 km^2 (calculated using Royal Australian Survey Corps Topographical Survey Map - sheet 7782), tide cycle = 6 hours, typical water level change per tide cycle = 2 m.

6.2.3 Interaction of Vessels with Marine Mammals and other Large Fauna

Issue

As discussed in Section 3.2.3, there are a number of species listed by the ICUN inhabiting the Gulf of Papua, such as dugongs, turtles and some species of whales and dolphins, which could be injured by collisions with project-related vessels.

The pipelaying vessel will operate with equipment (e.g., anchors and the pipeline itself) on the seafloor; consequently its ability to take avoiding action is limited.

Impact Assessment

Magnitude of Impact

The likelihood of collision between marine mammals and other large marine fauna with the vessels associated with the installation of the offshore pipeline is MINIMAL for the following reasons:

- The pipelaying vessel will travel at slow speeds (1 to 3 km per day), i.e., animals would have to collide with the vessel, not *vice versa*.
- While the support vessels and other project-related vessels will travel at greater speeds than the pipelaying vessel, they will be able to take avoiding action if a marine mammal is sighted.
- Sounds associated with the pipeline installation activities should temporarily deter marine mammals from entering the immediate areas of activity (see Section 6.2.4).
- Marine mammals, with the exception of dolphins, are not commonly seen in the parts of the Gulf of Papua traversed by the pipeline.

Any impact would be to individual animals very unlikely to affect a population of the species. For these reasons, the magnitude of impact is MINIMAL.

Sensitivity of Resource/Receptor

As discussed in Section 3.2.4, several marine animals that inhabit the Gulf of Papua are listed as vulnerable by the IUCN, however, the Gulf of Papua is not a known breeding area or special feeding ground for these species.

On the basis of the IUCN listing, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MINIMAL.

6.2.4 Underwater Noise

Issue

The pipelaying[11] and supporting vessels will operate 24 hours per day and emit underwater noise that will be characteristic of the source (engine size, thrusters, etc.) that will add to existing noise levels (see Section 2.6). Noises generated during pipelaying will have the potential to interfere with the behaviour of nearby marine mammals that communicate and/or navigate using sound.

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[11] At the time of writing, the use of an anchored laybarge and a dynamically positioned laybarge were both being considered by the project. For the purposes of assessing impacts relating to underwater noise, a dynamically positioned laybarge is used, as this type of vessel is noisier than an anchored laybarge.

Impact Assessment

This impact assessment is based on the specialist report prepared by Curtin University (2008). The report is provided as Annex A and a summary is provided below.

The assessment involved modelling the sound characteristics from a known vessel scaled to represent a dynamically positioned pipelay vessel. Sound attenuation was modelled at three points along the proposed offshore pipeline route as follows:

- One eastern point, near the Omati River end of the pipeline route, where the bottom sediment is silty.
- Two western points, near the Caution Bay end of the pipeline, where the bottom sediment is sandier.

Soft silty seafloors are generally more absorptive of sound, while the consolidated sandy seafloors to the east in Caution Bay are more reflective and intensity of propagation is slightly higher. Sound attenuation was modelled in two directions from the east point, i.e., up-slope (northwest) and down-slope (southeast), and four directions from the west points i.e., up-slope (northeast), down-slope (southwest) and across-slope (northwest and southeast).

Magnitude of Impact

While the vessel will be audible for greater than 20 km, the noise is too low (i.e., less than 180 dB) to produce detectable physiological effects on marine mammals, such as hearing threshold shifts. The level at which underwater noise is considered 'loud' is about 140 dB, which the modelling shows is limited to within 700 m of the vessel at the eastern point and within 2.2 to 2.3 km of the vessel at the western point. Even so, whales may exhibit avoidance behaviour at ranges of between 1 and 10 km from the vessel, with the larger avoidance distances to the eastern end of the route (because of the more sound-reflective seafloor).

The duration of the impact will be limited to when the pipelaying and trenching activities are being undertaken. Pipelaying is expected to progress at a rate of 1 to 3 km per day. Trenching (for the entire offshore pipeline) is scheduled to take approximately one year.

For reasons discussed above, the magnitude of impact is considered to be LOW.

Sensitivity of Resource/Receptor

As discussed in Section 3.2.4, several marine mammals that inhabit the Gulf of Papua are listed as vulnerable by the IUCN. Although the Gulf of Papua is not a known breeding area or special feeding ground for these species, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

6.2.5 Direct Disturbance to Seafloor Habitat

Issue

During the installation of the offshore pipeline, activities such as pipelaying, trenching and the placement of anchors associated with anchored laybarges[12] will disturb seafloor habitat. Once laid, seafloor could become scoured if localised lateral currents are sufficiently strong.

Impact Assessment

Magnitude of Impact

The extent of disturbance to seafloor habitat will be limited to the areas directly covered by and adjacent to the pipeline and where anchors are deployed. The area of disturbance along the pipeline route will be wider where trenching is undertaken. When anchoring barges, the typical area of disturbance from a single anchor behind the initial anchor drop point until the anchor holds is approximately 50 m^2. Anchor disturbance along the offshore route from pipelaying is expected to be approximately 33 ha[13]. The pipeline will physically cover approximately 43 ha of seafloor[14].

With the exception of the area physically covered by the pipeline, the disturbance to the seafloor habitat is expected to be very localised and temporary, leading to recovery in the short-term. The seafloors sampled along the route are characteristically described as silts and clays, typical of areas of deposition of river-borne sediment and unlikely to be susceptible to strong scouring forces. Engineering means to manage scouring and prevent spanning are available if there are any areas for which the geotechnical surveys (pre-installation) indicate that this might be necessary.

For these reasons, the magnitude of impact is considered to be MINIMAL.

Sensitivity of Resource/Receptor

As discussed in Section 3.1, the benthic habitats along the along the offshore pipeline route from the Omati River Landfall to the outskirts of Caution Bay are comprised mainly of a silts and clay with the occasional rocky outcrop and it is unlikely that large communities of sensitive habitat, such as coral or seagrass, would be present and no such areas were observed, until the route reaches Caution Bay.

The majority of the route from the Omati River Landfall to the approaches to Caution Bay is not route-sensitive to the extent that the same environments are crossed and impacts to benthos will be the same regardless of any deviations from the proposed route centreline.

As these habitats do not feature particular environmental significance, the sensitivity of resource/receptor is considered to be MINIMAL.

Assessment of Significance

The significance of this potential impact is considered to be MINIMAL.

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[12] At the time of writing, the use of an anchored laybarge and a dynamically positioned laybarge were both being considered by the project. For the purposes of assessing seafloor disturbance, an anchored laybarge is used, as this type of vessel would cause greater seafloor disturbance than a dynamically positioned laybarge.

[13] Assumptions: area of disturbance from each anchor = 50 m^2, number of anchors per anchored laybarge = 8, length of pipeline = 407 km, distance between each 'stop' of the anchored laybarge = 500 m.

[14] Assumptions: Diameter of pipeline = 0.85 m, thickness of pipeline external coating = 108 mm, length of pipeline = 407 km. This calculation does not take into consideration that some of the offshore pipeline will be buried.

6.2.6 Waste Discharge from Vessels

Issue

Water quality will be affected by the discharge of domestic wastes and deck wash from all vessels associated with pipeline installation and the transportation of equipment and supplies from Port Moresby to Kopi. Deck wash has the potential to be contaminated with oil.

The project will comply with the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978), which requires:

- Solid food waste to be macerated before disposal and be disposed of at least three nautical miles from shore.
- Sewage to be comminuted and disinfected before disposal and be disposed of at least three nautical miles from shore.
- Deck water potentially in contact with oily surfaces to be passed through oil/water separators before discharge overboard.

Impact Assessment

Magnitude of Impact

The MARPOL Convention requirements are applied routinely by vessels in similar situations to avoid unnecessary environmental impacts; hence assessment is made with the assumption of this condition. By adherence to MARPOL requirements, changes to water quality from the disposal domestic waste and deck wash of will be too localised and temporary to harm marine biota in this environment. Fish may be attracted to vessels disposing of food waste and elevated nutrient levels may locally increase plankton productivity.

For these reasons, the magnitude of impact is considered to be MINIMAL.

Sensitivity of Resource/Receptor

Treatment and discharge of waste waters according to international conventions will prevent any harmful effects to marine biota.

For these reasons, the sensitivity of resource/receptor is considered to be LOW.

Assessment of Significance

The significance of this potential impact is considered to be MINIMAL.

6.2.7 Accidental Spillage of Hazardous Substances

Issue

Hazardous and dangerous goods will be used on the pipelaying vessels, including diesel fuel, oxy-acetylene gas (for welding), solvents (for repair of corrosion coating), oxygen-reducing agents and corrosion inhibitors (additives to hydrotesting water) and X-ray sources (for radiography of pipeline welds). Accidental spillage of these substances, in particular a large-scale spill, such as that caused by a vessel collision, could impact the marine environment.

The project will comply with the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978), which requires:

- The development of a hazardous materials register.
- Separate storage of paints and other flammable materials.

- Wastes produced by vessels to be stored on board and then transferred to approved onshore facilities for treatment, reuse, recycling or disposal.
- Radioactive materials to be stored in suitable, adequately marked, purpose-built containers and to be handled by qualified personnel only.

Impact Assessment

Magnitude of Impact

The magnitude of impact is dependent on the volume and substance or substances that are spilled into the marine environment. The worst-case scenario, however unlikely, would be a vessel collision resulting in the spillage of a large quantity of fuel and other hazardous substances. A spill of this size could spread a great distance from the initial spillage site and have long-term impacts to marine biota (including fishery resources), particularly if a spill were to reach coastal areas.

While a large-scale spill may cause extensive long-term impacts to marine biota and fishery resources, such an event is unlikely to occur. Therefore, (without emergency/spill response planning), the magnitude of impact is considered to be MEDIUM.

Sensitivity of Resource/Receptor

Seafloor habitats along the area traversed by the offshore pipeline through the Gulf of Papua are not sensitive to spills. However, the Omati River and coastal areas that may be impacted in the event of a large-scale spill are more environmentally sensitive.

Local communities inhabiting coastal areas and prawn trawl operators would be sensitive to impacts to fisheries resources, as these stakeholders heavily rely on these resources for their livelihood.

For these reasons, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MODERATE.

6.2.8 Interaction with Commercial Fisheries

Issue

Fishing boat operators will have to keep clear of vessels involved in the installation of the pipeline and observe a 500 m safety exclusion zone around the pipeline installation vessel. Fishing boat skippers will need to select alternative locations to obtain their catches if, at any time, the pipeline construction activities pass through their preferred fishing grounds. It is likely that this will mainly apply to prawn trawling operations, as the offshore pipeline route traverses prawn trawling grounds (see Section 4.2).

Barges travelling between Port Moresby and Kopi will add to existing levels of shipping traffic in the area and these barges will need to keep clear of fishing vessels actively fishing, as other vessels transiting the Gulf of Papua currently do.

Impact Assessment

Magnitude of Impact

The fishery grounds in question are extensive in relation to the small, temporary and moving safety exclusion zone, and so any inconvenience will be highly localised and of very short duration.

The barges travelling between Port Moresby and Kopi will add to the existing level of commercial shipping in the area, however, maritime regulations exist to mitigate interactions between commercial vessels.

On this basis, the magnitude of impact is considered to be LOW.

Sensitivity of Resource/Receptor

As discussed in Section 4.2, the number of prawn trawlers operating in the Gulf of Papua has declined in recent years due to the increased cost of fuel and subsequent decreased profitability of the fishery. The industry is currently vulnerable and reduced catch rates or increased fuel usage could decrease the number of trawlers operating.

For these reasons, the sensitivity of resource/receptor is considered to be MEDIUM.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

6.2.9 Interaction with Subsistence Fisheries and Small Craft

Issue

As with commercial vessels, operators of small craft, such as canoes and banana boats, will have to keep clear of vessels involved in the installation of the pipeline. Local villagers will need to select alternative fishing areas if, at any time, the pipeline construction activities pass through their preferred fishing grounds.

A hazard may apply to villagers if, out of curiosity, their craft approach too close to the pipeline installation vessels.

Waves caused by the barges travelling through the Omati-Kikori delta have the potential to swamp small craft, such as banana boats and canoes. In addition, local people would not be able to fish using nets along the barge route while barges are passing through.

Impact Assessment

Magnitude of Impact

The geographic extent of this issue is limited to areas where small craft operate, such as in the Omati River and a short distance out from the Omati River mouth. The duration of this impact will be short, i.e., the duration of pipelaying in the area in question. Pipelaying activities in the Omati River are expected to progress at a rate of 300 to 720 m per day. Pipelaying offshore in the Gulf of Papua will be faster, progressing at a rate of 2 to 3 km per day. There is a high probability that this impact will occur. There are numerous fishing areas in creeks and tributaries for alternative fishing during the time that the vessel is in any particular area.

People currently using the barging route would be accustom to dealing with marine traffic, as the route proposed by the project is currently used by barges bringing supplies to Kopi and Kikori. Fishing, as observed during a resource use survey undertaken in April 2008 (Coffey Natural Systems, 2008b) was limited along the barge route and much greater levels of fishing activity were observed in areas were barges were not known to traverse. Therefore, the increase in quantity of barge traffic is unlikely to affect resource use along the barging route.

On this basis, the magnitude of impact is considered to be MEDIUM.

Sensitivity of Resource/Receptor

As described in Section 4.4, subsistence fishing provides an essential source of daily food for local villagers near the Omati River Landfall. In addition, the only access to and from these villages is via boat.

For these reasons, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MODERATE.

6.2.10 Interference with Tropical Rock Lobster Migration

Issue

Adult tropical rock lobsters undertake annual migrations from the reefs of the Torres Strait and the northern Great Barrier Reef across the Gulf of Papua to the reefs off Yule Island and further to the east (see Figure 4.5). This takes place from August to December each year and is related to spawning (see Section 4.3.2). As construction of the offshore pipeline is anticipated to take approximately 16 months, it will coincide with at least one migration/breeding season.

Once installed, the offshore pipeline will present a potential obstacle to their migratory route as the lobsters migrate along the seafloor and do not swim in the water column.

Impact Assessment

Magnitude of Impact

During construction, rock lobsters would likely be injured or killed if the pipeline happened to be laid on them as they migrated across the Gulf of Papua, however, it is likely that only a few individuals would be affected and this is unlikely to result in changes to the overall population.

The ability of tropical rock lobsters to crawl over a pipeline has been demonstrated (NSR, 1998), and therefore the presence and operation of the pipeline (during operation) is not likely to interfere with the annual rock lobster migration.

On this basis, the magnitude of impact is considered MINIMAL.

Sensitivity of Resource/Receptor

Disruption to rock lobster migration would not only reduce the catch rates of areas fished to the north of the pipeline, but it may also affect breeding as the migration is related to spawning. Disruption of breeding may affect the overall rock lobster population that would in turn affect the commercial rock lobster fishery.

On this basis, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MINIMAL.

6.2.11 Interference with Shipping

Issue

Commercial shipping vessels will have to keep clear of vessels involved in the installation of the pipeline and observe a safe buffer zone around the pipeline installation vessel. If, at any time, the pipeline construction activities pass through their preferred navigational route, the commercial shipping vessels will need to slightly deviate from their course to keep outside the 500 m safety exclusion zone.

Impact Assessment

Magnitude of Impact

The Gulf of Papua is a large body of water and there are many routes that commercial shipping vessels can use to cross the area. The observance of the safety exclusion zone is unlikely to add additional time to the voyages of the commercial shipping vessels.

In contrast, the number of routes available to large commercial vessels travelling through the Omati River is limited. Observance of a safety exclusion zone in the Omati River is likely to cause inconvenience to commercial vessels travelling through the area.

On this basis, the magnitude of impact is considered LOW in the Gulf of Papua and MEDIUM in the Omati River.

Sensitivity of Resource/Receptor

Commercial shipping vessels can alter course to avoid pipelaying activities and keep outside the safety exclusion zone in the Gulf of Papua. In the Omati River, the ability to alter course is more limited, in particular areas where water depth sufficient for large vessels may be restricted to the main river channel.

On this basis, the sensitivity of resource/receptor is considered to be LOW in the Gulf of Papua and MEDIUM in the Omati River.

Assessment of Significance

The significance of this potential impact is considered to be MINOR in both the Gulf of Papua and in the Omati River.

6.2.12 Entanglement of Anchors or Fishing Gear with Pipeline

Issue

The pipeline will cross the prawn trawling grounds, so there is a potential for anchors or fishing gear (e.g., ropes, cables and nets) to become snagged on the pipeline, with an associated risk of loss of gear and potential risk to the safety of vessel and crew. The pipeline will be concrete-coated and is therefore not susceptible to damage from conventional fishing gear or anchors of a size utilised by large vessels typically found in the Gulf of Papua.

Impact Assessment

Magnitude of Impact

The likelihood of anchors or fishing gear to becoming entangled with the pipeline is low for following reasons:

- The pipeline is expected to self-bury for most of its length in soft sediments, such as those found in the prawn trawling grounds, based on a pipeline inspection and maintenance program survey undertaken in 2002 of the existing 88-km–long crude oil export pipeline servicing the Kumul Marine Terminal operated by Oil Search Limited, which has self-buried for approximately half its length.
- The project will employ span reduction methods, such as trenching or grout bag support, if there are any areas where spanning of the pipeline could occur. These areas will be determined following interpretation of the findings of a detailed geophysical survey, during a presweep survey performed immediately prior to pipelaying, and in a post-installation inspection.

- As-laid information will be available to trawler operators so that they can avoid any anchoring in the vicinity.
- The pipeline will be actively buried at the Omati River and Caution Bay ends of the offshore pipeline, in water depths below 5 m to 10 m and 15 m, respectively.

Shipowners who can prove that they have sacrificed gear fastened on an undersea pipeline can be compensated under Article 29 of the 1958 Convention on the High Seas, Article VII of the Submarine Telegraphs Convention of 1884. Therefore, any impacts to shipowners in the unlikely event that their anchor or fishing gear becomes entangled with the pipeline are limited to the inconvenience of applying for compensation and having to return to port with a partial catch.

Trawling over pipelines occurs in many places in the world with low risk where engineering design and management and communication measures are effective.

On this basis, the magnitude of impact is considered LOW.

Sensitivity of Resource/Receptor

As discussed in Section 4.2, the number of prawn trawlers operating in the Gulf of Papua has declined in recent years due to the increased cost of fuel and subsequent decreased profitability of the fishery. The industry is currently vulnerable and loss of fishing gear and/or anchors could decrease the number of trawlers operating. There is also a potential safety risk to vessel and crew in the event of trawl gear hooking up on bottom obstructions such as pipelines, if gear is not released or power disengaged quickly.

For these reasons, the sensitivity of resource/receptor is considered to be HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

6.2.13 Quarantine

Issue

A potential pathway for the introduction of non-native marine flora and fauna into PNG waters is the presence of non-native organisms in ballast water or on the hulls of project-related vessels. Marine pests cause problems to ecosystems through competition with existing native species for resources, alteration of localised gene pools and modification of physical environments.

The project will adhere to International Maritime Organization (IMO) requirements and industry good practice with respect to ballast water discharge and hull cleaning.

Impact Assessment

Magnitude of Impact

As the project will adhere to IMO requirements and industry good practice, it is unlikely that non-native organisms will be introduced into PNG waters via ballast water or on the hulls of project-related vessels

In the unlikely event that this was to occur, the impact may be extensive (i.e., the organism or organisms may spread to other parts of PNG) and long-term (i.e., it is often not possible to eradicate introduced marine pests).

On this basis, the magnitude of impact is considered MEDIUM.

Sensitivity of Resource/Receptor

The susceptibility of tropical waters, such the Gulf of Papua, to the introduction of non-native marine pests is lower than temperate waters, as topical waters have a high diversity of species and, as a result, have fewer niches for pest species to occupy. Most tropical species have a wide distribution, so the risks of local introductions of species not already there, or of temperate species becoming established is low. However, non-native marine pests can still be introduced into tropical waters and an example is the introduction of the black-striped mussel (*Mytilopsis sallei*) to marinas in Darwin, Australia in 1999 (Marshall et al., 2003).

For these reasons, the sensitivity of resource/receptor is considered to be LOW.

Assessment of Significance

The significance of this potential impact is considered to be MINOR.

6.2.14 Light Emissions

Issue

The vessels associated with construction of the offshore pipeline will operate 24 hours per day using artificial lighting, which will have the potential to attract marine fauna including seabirds, fish, squid and larger predatory species.

Impact Assessment

Magnitude of Impact

Lighting at night will attract fish and other marine animals, but this will move with the operation at a rate of 1 to 3 km per day, hence will not become a fixed fish attracting structure. Being so far offshore the light is not likely to affect orientation of turtles moving to or from nesting beaches and no adverse impacts to flora and fauna are therefore predicted. Hence, magnitude of impact is MINIMAL.

Sensitivity of Resource/Receptor

As discussed in Sections 3.2.2 and 3.2.3, several species of turtle and marine mammals that inhabit the Gulf of Papua are listed by the IUCN. The route is predominantly well offshore of land and the offshore Gulf of Papua is not a known breeding area or special feeding ground for these species. As they may occur, the sensitivity of resource/receptor is HIGH.

Assessment of Significance

The significance of this potential impact is considered to be MINIMAL.

7. RECOMMENDATIONS

The following measures are recommended to assist in the mitigation of the potential issues described in Chapter 6.

7.1 Implementation of a Marine Mammal Observation Procedure

A marine fauna observation procedure should be implemented. This procedure would require all observations and encounters with marine mammals (such as whales and dugongs) and turtles to be documented in an observation log, which would also be used to warn the vessel crew of any whale or dugong activity within close proximity (e.g., 500 m) of the pipelaying and support vessels. If this occurs, options to stop pipelaying activities or reduce the speed of the pipelaying vessels are not practicable, however, support vessels will be able to take avoiding action or help to head off any inquisitive animals approaching too close to the pipelay activities.

7.2 Development of an Emergency Response Procedure

An Emergency Response Procedure appropriate to the phase of the project should be developed and this procedure should be introduced to personnel on the offshore pipelaying vessels on induction. Resources required for responding to a spill should be made available by the project and identified in this procedure. In the unlikely event of a spill (such as that caused by a vessel collision), the utilisation of an adequate Emergency Response Procedure (along with appropriate resources) would significantly lessen the severity of impact to the environment.

7.3 Notification of Local Communities and Commercial Fishing Fleets about Construction Activities

A community awareness program should be carried out to inform inhabitants of villages near the offshore pipeline route (this will mainly apply near the landfall locations) of the offshore pipeline construction activities, including timing and the dangers associated with approaching pipelaying vessels. Villagers should be requested to remain clear of the pipelaying vessels for their own safety.

Likewise, NFA and commercial fishing fleets that operate in the vicinity of the offshore pipeline route should be informed about offshore pipeline construction activities, including likely timing and the safety exclusion zone.

This will reduce the inconvenience to those undertaking commercial fishing activities, as they will know in advance where they can fish and avoid travelling to fishing grounds in the vicinity of the offshore pipeline route when pipelaying activities are being undertaken.

7.4 Notification of Local Communities about Project Barge Traffic

A community awareness program should be carried out to inform inhabitants of villages along the proposed barging route through the Omati-Kikori delta about project barge traffic and the associated dangers of approaching barges too closely.

7.5 Provision of Pipeline Location to PNG Hydrographer's Office

Information on the pipeline location as laid should be provided to the PNG hydrographer's office for incorporation into navigation charts. This will assist in reducing the likelihood of anchors or fishing gear becoming snagged with the pipeline, as non-project vessels using navigation charts will be aware of where the pipeline has been laid and will therefore be able to avoid undertaking activities in this area that may cause damage to their equipment.

7.6 Minimisation of Deck Lighting

Decking lights on project-related vessels should be kept to the lowest levels needed to maintain safe working conditions to minimise the amount of light emissions into the marine environment. Lighting is required for safety and operational purposes and it is not practicable to avoid the use of lighting.

8. SUMMARY

A summary of the potential issues associated with construction and operation of the offshore pipeline, an impact assessment and recommendations for the project are provided in Table 8.1.

Table 8.1 Summary of issues, pre-mitigation impact assessment and recommendations

Potential Issue	Pre-Mitigation Impact Assessment			Recommendation
	Magnitude of Impact	Sensitivity of Resource/Receptor	Significance	
Increased suspended sediment and sedimentation rates	Low	Low	Minor	
Disposal of hydrotest water	Low	Low	Minor	
Interaction of vessels with marine mammals and other large fauna	Minimal	High	Minimal	Implementation of a marine fauna observation procedure.
Underwater noise	Low	High	Minor	
Direct disturbance to seafloor habitat	Minimal	Minimal	Minimal	
Waste discharge from vessels	Minimal	Low	Minimal	
Accidental spillage of hazardous substances	Medium	High	Moderate	Development of an Emergency Response Procedure.
Interaction with commercial fisheries	Low	Medium	Minor	Notification of local communities and commercial fishing fleets about construction activities
Interaction with subsistence fisheries and small craft	Medium	High	Moderate	Notification of local communities and commercial fishing fleets about construction activities. Notification of local communities about project-related barge traffic.
Interference with tropical rock lobster migration	Minimal	High	Minimal	
Interference with shipping (Gulf of Papua)	Low	Low	Minor	
Interference with shipping (Omati River)	Medium	Medium	Minor	
Entanglement of anchors or fishing gear with pipeline	Low	High	Minor	Provision of pipeline location to PNG Hydrographer's Office.
Quarantine	Medium	Low	Minor	
Light emissions	Low	High	Minor	Minimisation of deck lighting.

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Annex A

Prediction of Underwater Noise Produced by a Pipelaying Operation in the Gulf of Papua and its Likely Effects on Marine Animals

Curtin

UNIVERSITY OF TECHNOLOGY

Centre for Marine Science and Technology

Prediction of underwater noise produced by a pipelaying operation in the Gulf of Papua and its likely effects on marine animals

By:
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Prepared for:
Coffey Natural Systems

PROJECT CMST 759
REPORT 2008-25

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Abstract

This report presents the results of numerical modelling of the propagation of underwater noise produced by a proposed pipeline laying operation in the Gulf of Papua, New Guinea. It is expected that the dominant source of noise will be cavitation of the pipelaying vessel's thrusters while on dynamic positioning, and modelling has therefore focussed on this noise source.

Predicted sound levels are significantly lower over the muddy seabeds found in the western portion of the pipeline route than over the sandy seabeds found in the eastern portion.

Sound levels are unlikely to be high enough to produce detectable physiological effects in marine animals, but may result in some avoidance behaviour at ranges of between 1km and 10 km, with the shorter ranges corresponding to the western portion of the route. The levels may also produce some masking of relatively low level sounds, many marine animals use as part of their normal behaviour.

Table of Contents

List of Figures

List of Tables

1 Introduction

This report presents the results of numerical modelling of underwater sound levels from a proposed pipeline laying operation in the Gulf of Papua (see Figure 1) and a discussion of the likely impacts of these levels on any marine mammals in the area.

Although there would be a variety of sound sources involved in such an operation, previous underwater sound measurements made by one of the authors during other offshore operations (McCauley 1998) indicate that cavitation noise produced by the thrusters on the pipelay vessel is likely to be the most significant. This will particularly be the case if a dynamic positioning (DP) vessel is used. The modelling work presented here therefore focuses on the prediction of this type of noise.

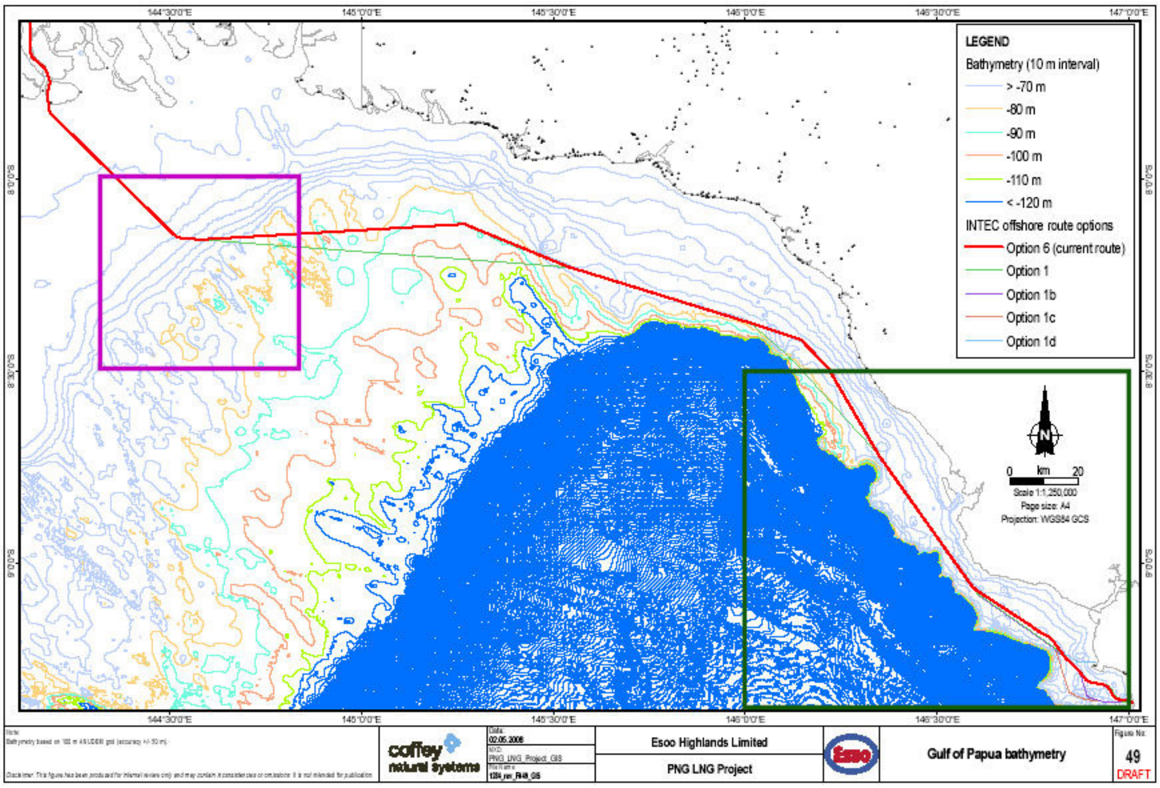

Figure 1. Geographical location of the proposed pipeline (red) showing bathymetry. Rectangles show the locations of East (dark green) and West (magenta) regions considered later in the report. (Base map provided by Coffey Natural Systems.)

2 Methods

To predict received levels due to any underwater source it is first necessary to determine the characteristics of the source signal.

2.1 Source modelling

Cavitation in water occurs when the pressure in a particular location drops below the saturated water vapour pressure. Bubbles of water vapour then form - the water effectively boils, but due to a lowering of pressure, rather than the increase in water vapour pressure with temperature. When these bubbles move into a region of higher pressure they implode violently, producing a sharp, impulsive sound.

For a propeller, there is a low pressure region on the forward face of each blade which can (and usually does) result in the continuous formation of cavitation bubbles, which subsequently move into a region of higher pressure and implode. The combined effect of the implosion of many cavitation bubbles is high intensity, broadband noise, usually modulated at the propeller blade rate (the shaft rotation rate multiplied by the number of blades).

Because of its importance for passive sonar detection of ships and submarines, cavitation noise has been extensively studied (see eg. Ross, 1987), however this has been in the context of ships travelling at speed, rather than ships holding station on DP. The source model used in this report is therefore based on measurements made by one of the authors of underwater sound levels produced by a rig tender (*Pacific Ariki*) on DP (McCauley 1998). The characteristics of the *Pacific Ariki* are given in Table 1, and the measured, third octave source spectrum is shown in Figure 2. The Pacific Ariki is a much smaller vessel than typical pipelay vessels (see Table 1). Levels have therefore been extrapolated to those to be expected for a larger vessel by assuming that a constant proportion of the mechanical power is converted to acoustic power. This relationship has been found to hold reasonably well for surface vessels operating at their normal cruising speed (Ross 1987). The source level corrections given in Table 1 are therefore given by:

$$Correction = 10\log_{10}\left(\frac{P_{vessel}}{P_{Ariki}}\right) \quad \text{(dB)}$$

where P_{vessel} is the total installed thruster power on the vessel, and P_{Ariki} is the total installed thruster power on *Pacific Ariki*. The larger of the two corrections listed in the table (8.8 dB) was used for the received level calculations. The resulting source spectrum is shown in Figure 2.

This *Pacific Ariki* spectrum is based on measurements made in a single direction relative to the vessel, so no source directionality data is available. However, given the nature of cavitation noise, and the fact that the thrusters are located at different positions on the vessel, and in many cases can be rotated in azimuth, it is reasonable to assume that it is omnidirectional.

Based on the expected vessel draft, the source was assumed to be at a depth of 5 m below the water surface.

Table 1. Characteristics of the *Pacific Ariki* and two of the vessels under consideration for the pipelay operation.

Vessel	**Pacific Ariki**	**Global Hercules**	**Global 1200**
Length Over All	64 m	148 m	162.3 m
Operating draft	6.6 m	3.66 m - 5.49 m	5.8 m to 6.6 m
Tonnage	2,600 (displacement)	18,588 (gross)	25,000 (displacement)
Propulsion power	4 x 1500 kW = 6,000 kW	0	2 x 4,500 kW = 9,000 kW
Retractable thrusters	1 x 600 kW	6 x 2,237 kW = 13,422 kW	5 x 2,400 kW = 12,000 kW
Tunnel thrusters	2 x 600 kW = 1200 kW	0	1 x 880 kW
Total thruster power	1800 kW	13,422 kW	12,880 kW
Total thruster power relative to Pacific Ariki	1	7.5	7.2
Source level dB correction	0 dB	8.8 dB	8.6 dB

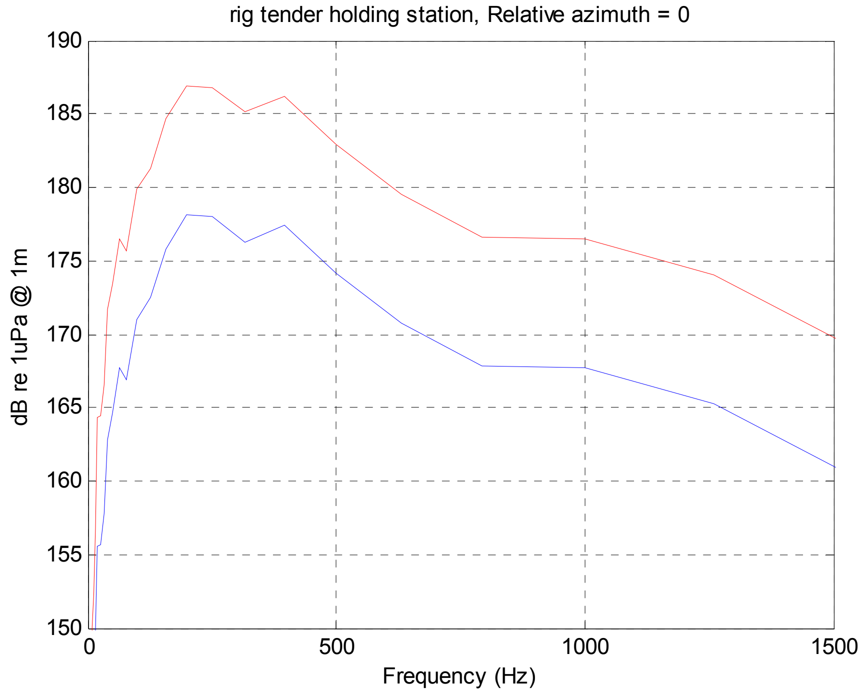

Figure 2. Third octave source spectra. Blue - measured spectrum of the *Pacific Ariki*, red - extrapolated spectrum for a typical pipelay vessel.

2.2 Propagation modelling

Information provided by Coffey Natural Systems indicated that the seabed along the western part of the pipeline route was essentially mud (silt), whereas in the eastern portion the seabed was sand, progressively becoming coarser towards the pipeline's south-eastern end. Acoustically sand is more reflective than silt, with coarse sand being more reflective than fine sand. It was therefore decided to concentrate the modelling effort on the south-eastern end of the pipeline route as this was expected to represent the conditions under which the highest received levels would occur. Propagation modelling was therefore carried out along four azimuths centred on each of the two points (P1 and P2) shown in Figure 3. The points were chosen at positions along the pipeline route close to the sharp drop-off into deep water that occurs in this region, so that the effect of this drop-off could be investigated. Azimuths were chosen to be up-slope, down-slope and across-slope. Modelling was carried out using the medium/coarse sand properties listed in Table 2, which are a combination of the information from Hamilton (1980) and Jensen (2000).

For comparison purposes propagation modelling was also carried out for one location along the western part of the pipeline route: P3 in Figure 4, in this case using the silt seabed properties in Table 2 which are from Jensen (2000).

The bathymetry profiles used for the various model runs are shown in figures 5 to 7, and the sound speed profile, obtained form the World Ocean Atlas, 2005, is shown in Figure 8.

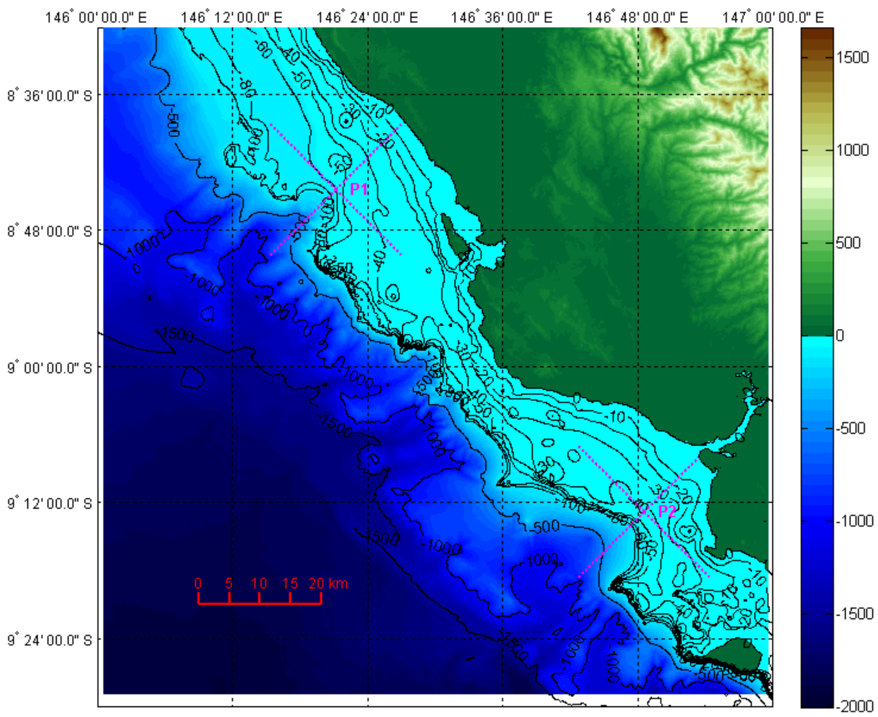

Figure 3. Bathymetry and propagation modelling locations for the Eastern Gulf of Papua region considered in this study. The dotted magenta lines show the bathymetry profiles used for the propagation model runs.

Table 2. Seabed acoustic data used in propagation modelling.

Material	**Density ($kg.m^{-3}$)**	**Compressional wave speed (m/s)**	**Compressional wave attenuation (dB per wavelength)**
Medium/coarse sand	2000	1800	0.8
Silt	1700	1575	0.1

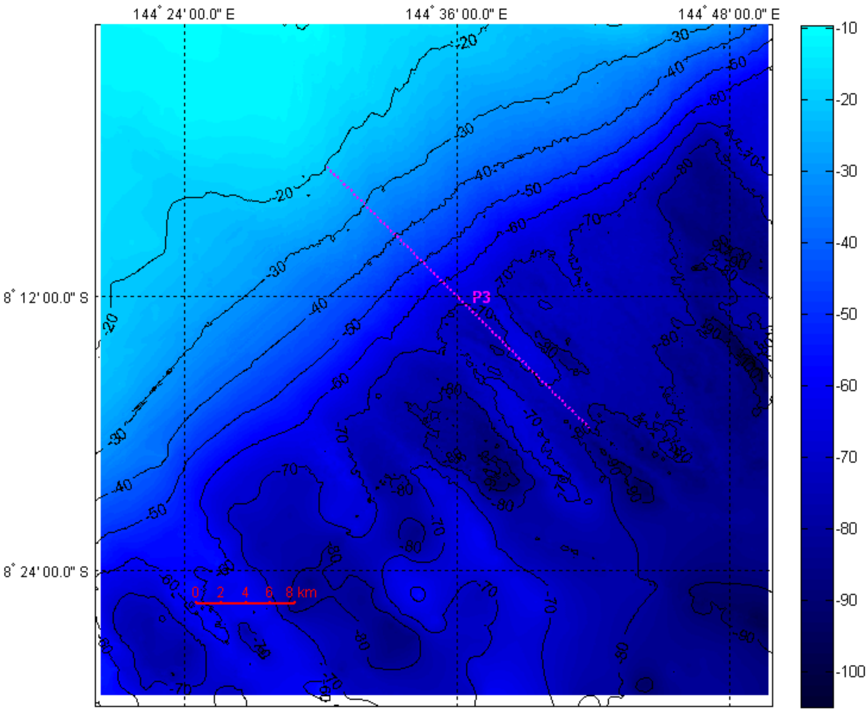

Figure 4. Bathymetry and propagation modelling locations for the Western Gulf of Papua region considered in this study. The dotted magenta lines show the bathymetry profiles used for the propagation model runs.

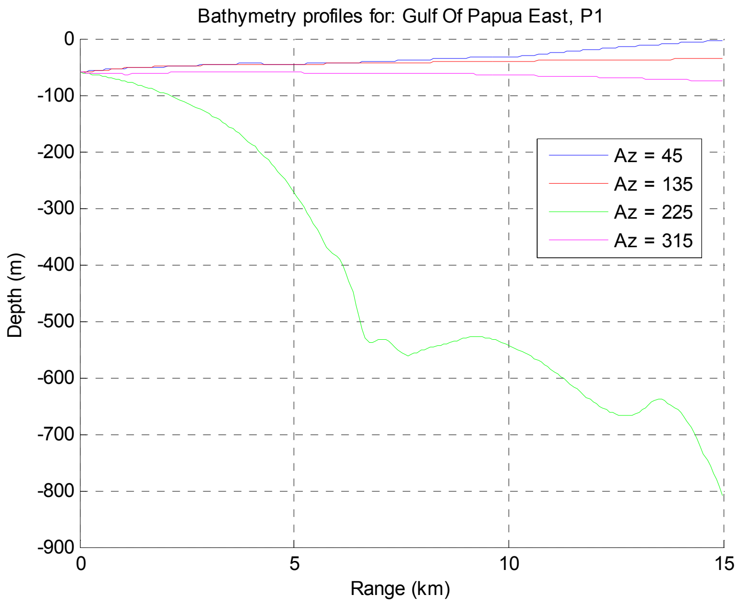

Figure 5. Bathymetry profiles used for propagation modelling for source location P1.

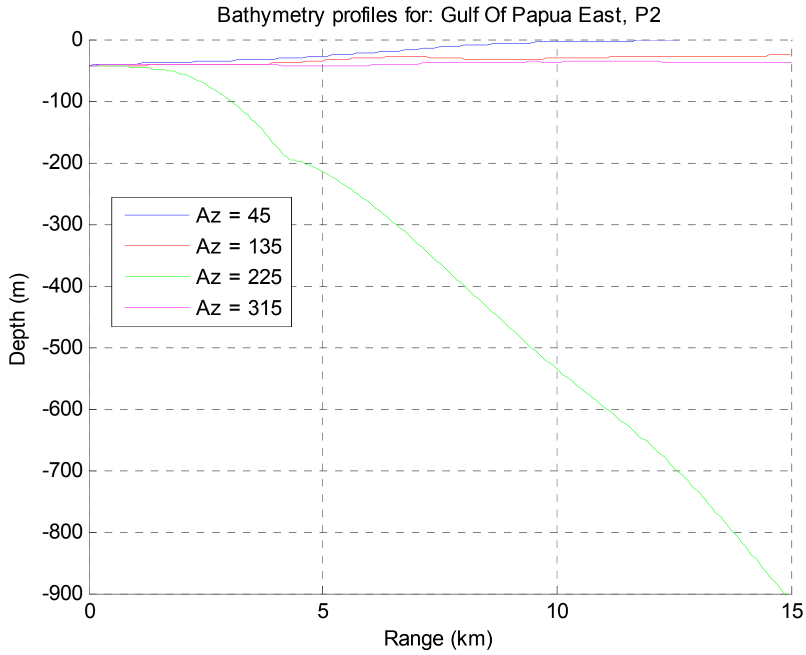

Figure 6. Bathymetry profiles used for propagation modelling for source location P2

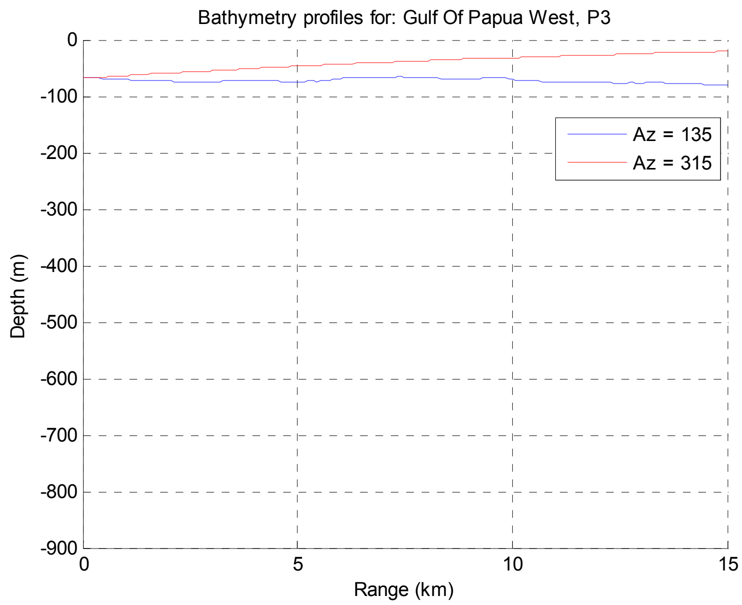

Figure 7. Bathymetry profiles used for propagation modelling for source location P3

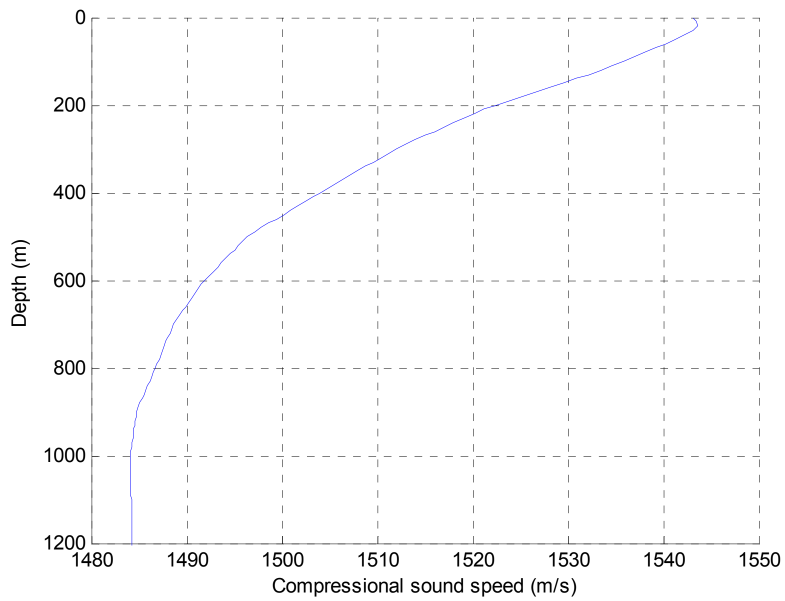

Figure 8. Water column sound speed profile used for propagation modelling.

The parabolic equation propagation model, RAMGeo, written by Mike Collins from the US Naval Research Laboratory, was chosen for this modelling work as it can reliably deal with the range dependent fluid seabed models used here.

2.3 Received level calculations

Received levels were calculated for each bathymetry track of each source point as follows:

- The propagation model was run to obtain transmission loss as a function of range and depth for frequencies spaced at 1/3 octave intervals from 8 Hz to 1 kHz.
- The azimuth of each propagation path relative to the array was determined by taking account of the stated survey line directions.
- The source level at each of these frequencies was obtained by integrating the source spectrum for the appropriate azimuth over a 1/3 octave frequency band centred on the desired frequency.
- The source level and transmission loss were then combined to compute the received level as a function of range and depth for a grid of points covering the length of the propagation track (15 km) to a depth of 400 m. Range increments

were 10 m out to a range of 1 km, and 100 m at longer ranges. Depth increments were 1 m from the surface to 100 m depth, then 10 m at deeper depths.

3 Results

Plots of the received level as a function of range and depth out to the maximum modelled range of 15 km are given in figures 9 to 11. For the shallow water propagation paths the received level varies very little with depth, however the paths that extend into deep water show the effects of the strongly downwardly refracting sound speed profile, which results in the higher sound levels remaining close to the seabed. The deepwater path from P1, shown in the bottom left plot of Figure 9, shows the sound being reflected back up to the surface from a plateau at about 600 m depth. The sound is then directed back towards the seabed by a combination of downward refraction due to the sound speed gradient, and reflection from the sea surface.

Zoomed versions of the same plots, covering horizontal ranges of 0 to 3 km and depths from 0 to 150 m are shown in figures 12 to 14. These zoomed plots show that the rate of decay of received level with range is very similar out to 3 km for all azimuths for points P1 and P2. However, as expected, the softer seabed at P3 results in a much more rapid decay.

The effect of the seabed composition is shown more clearly in Figure 15, which shows received levels as a function of range for each of the source points. The results for P1 and P2 are almost indistinguishable on this plot, whereas the received levels for P3 are lower at all ranges, with the difference increasing with increasing range.

A more statistical presentation of the data is given in Figure 16 (source points P1 and P2) and Figure 17 (source point P3). These plots show the percentage of locations with a received level less than or equal to a specified threshold as a function of horizontal range. The ranges at which the 95% threshold is crossed are given in Table 3.

Table 3. Range beyond which 95% of received levels are expected to be below the specified threshold.

Threshold	160 dB re 1 μPa	150 dB re 1 μPa	140 dB re 1 μPa
Source point			

P1	90 m	560 m	2200 m
P2	120 m	680 m	2300 m
P3	88 m	260 m	700 m

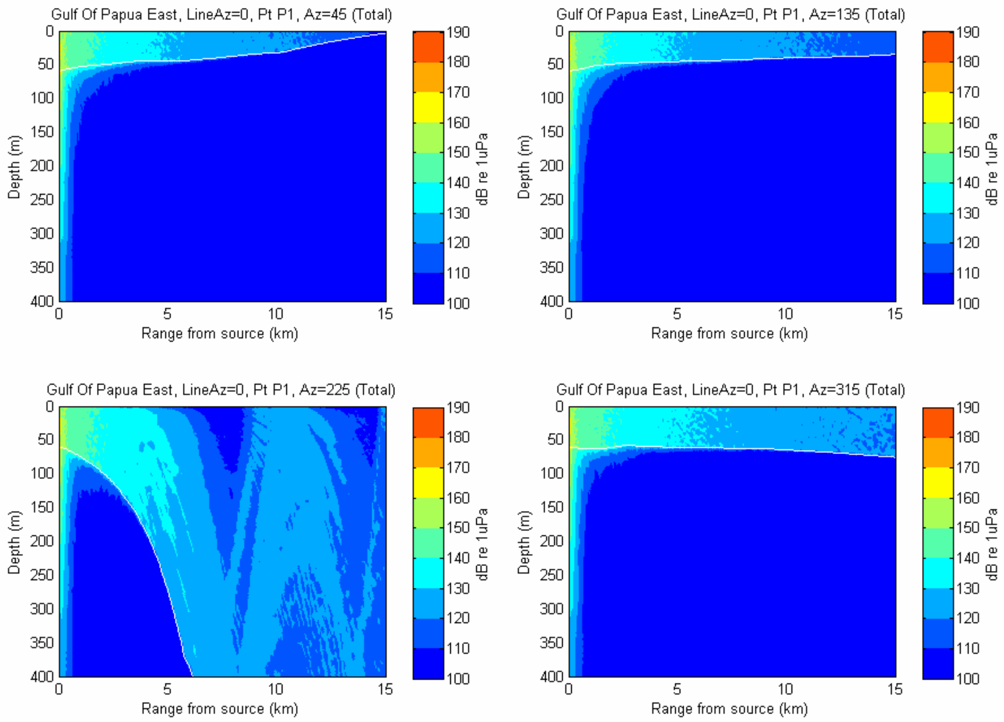

Figure 9. Plots of predicted received level vs. range and depth for four different azimuths from source point P1.

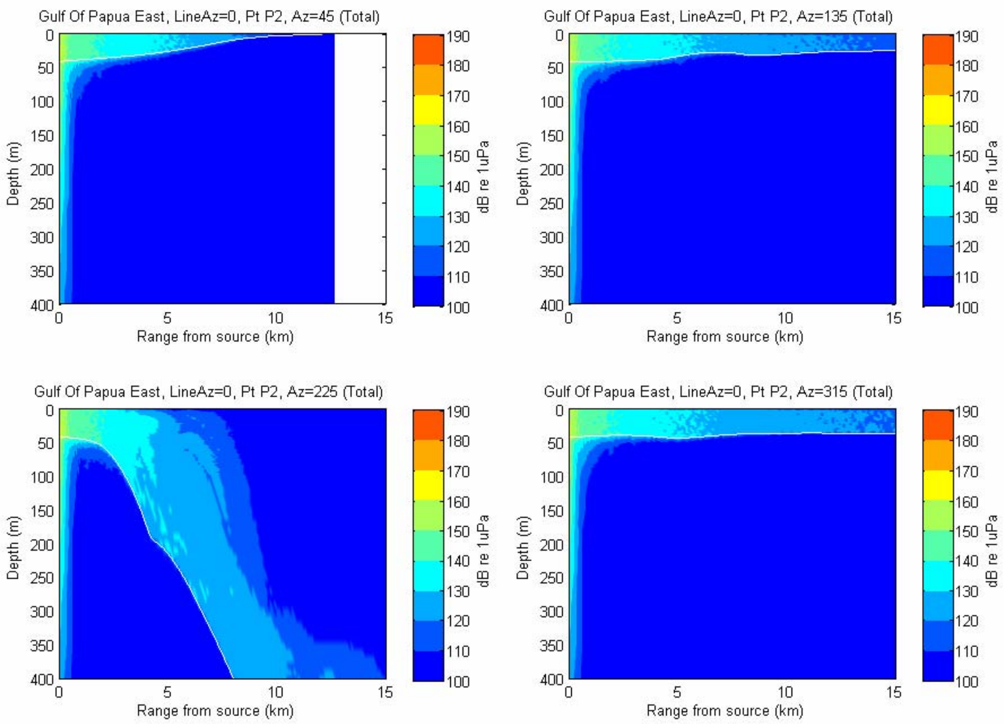

Figure 10. Plots of predicted received level vs. range and depth for four different azimuths from source point P2.

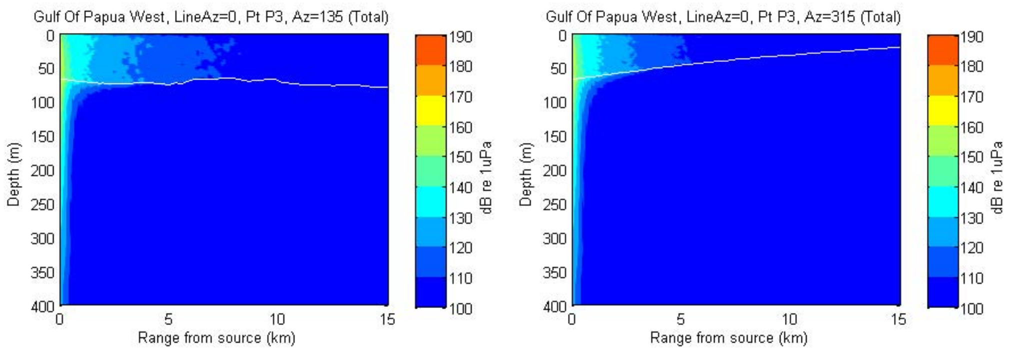

Figure 11. Plots of predicted received level vs. range and depth for two different azimuths from source point P3.

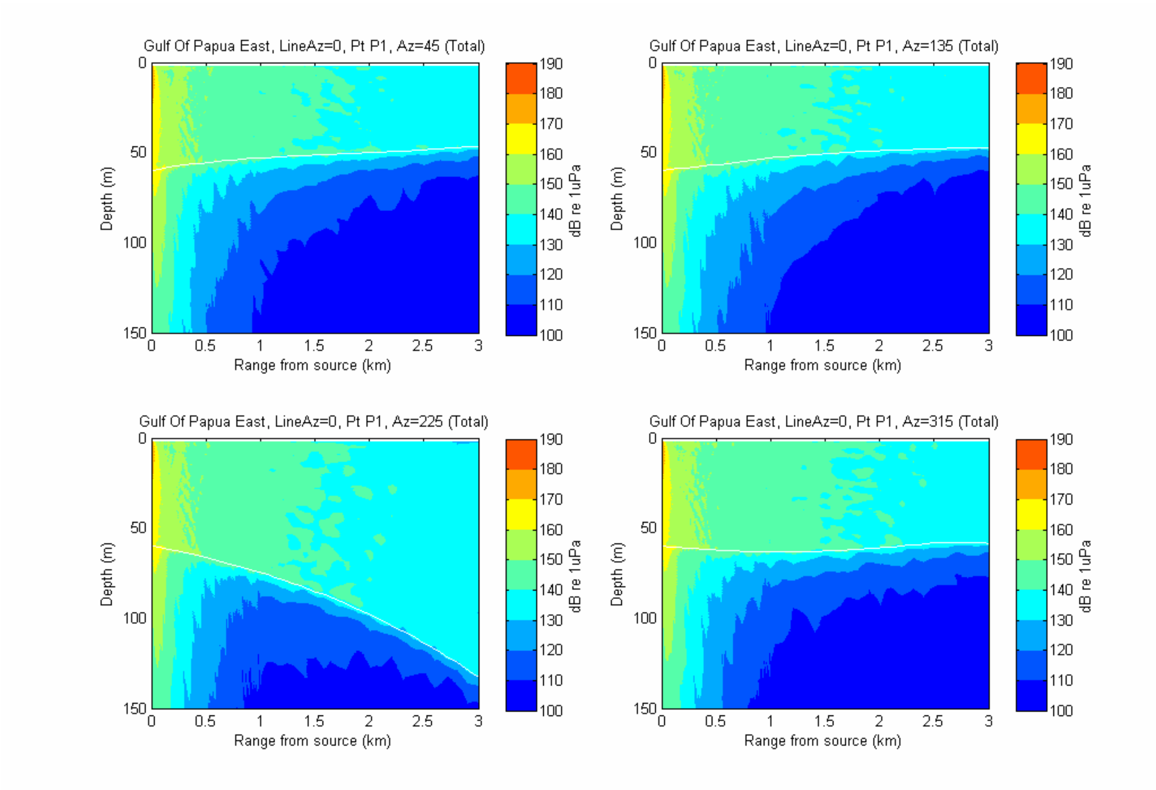

Figure 12. Zoomed view of plots of predicted received level vs. range and depth for four different azimuths from source point P1.

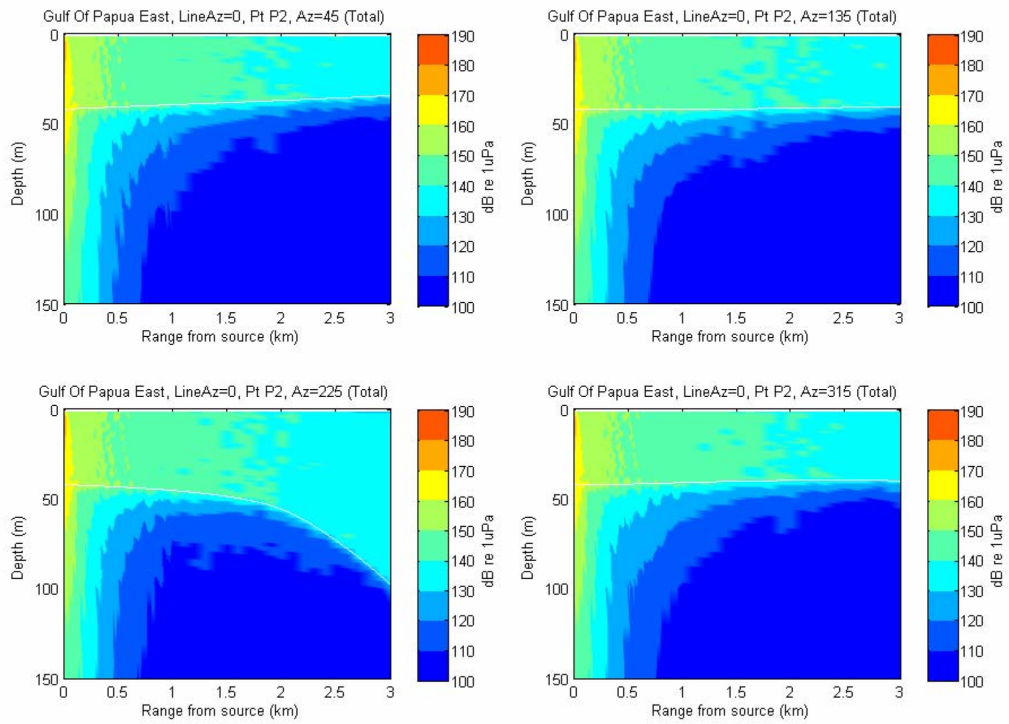

Figure 13. Zoomed view of plots of predicted received level vs. range and depth for four different azimuths from source point P2.

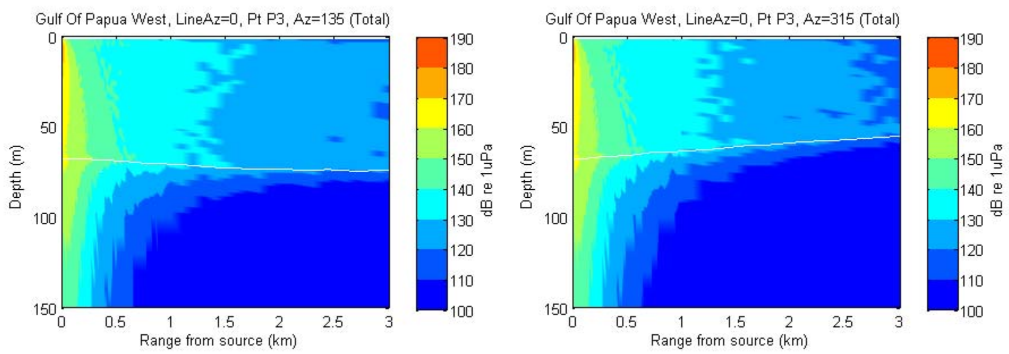

Figure 14. Zoomed view of plots of predicted received level vs. range and depth for four different azimuths from source point P3.

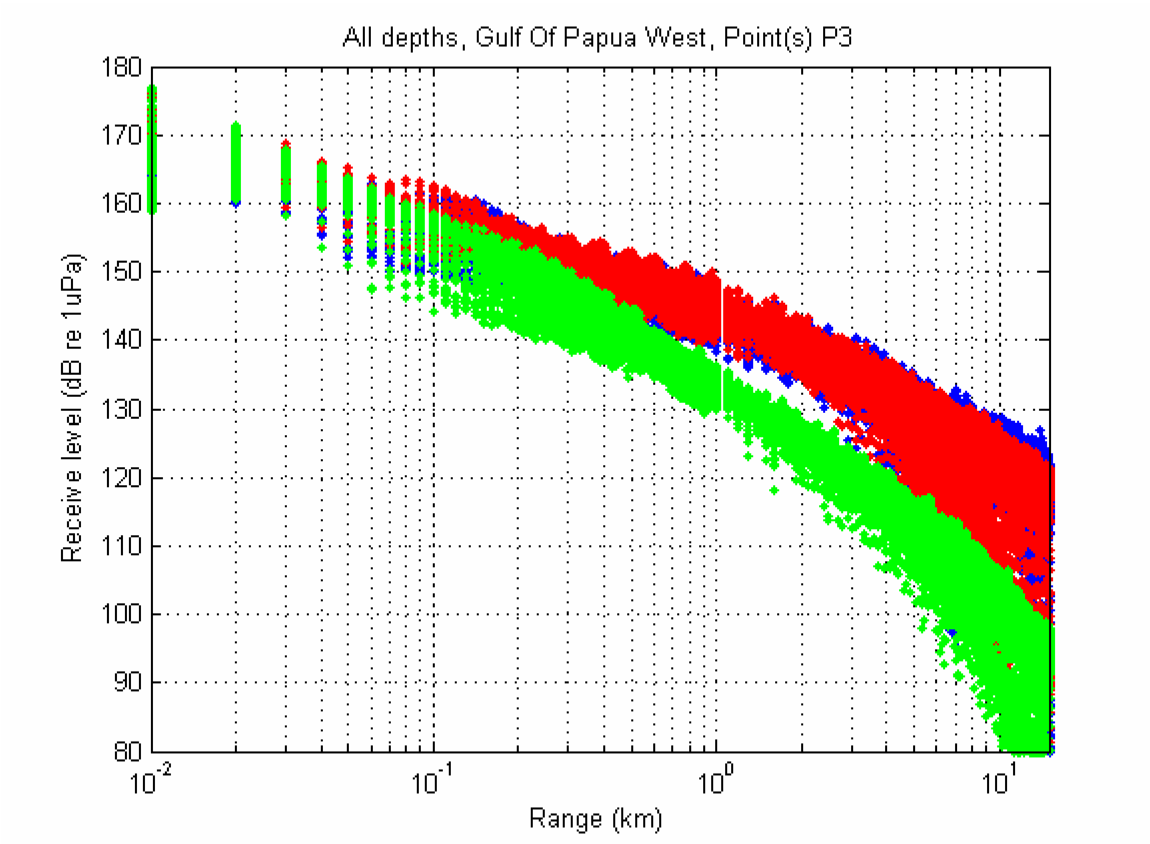

Figure 15. Scatter plot of received levels as a function of range for all depths and azimuths for source points P1 (blue), P2 (red) and P3 (green).

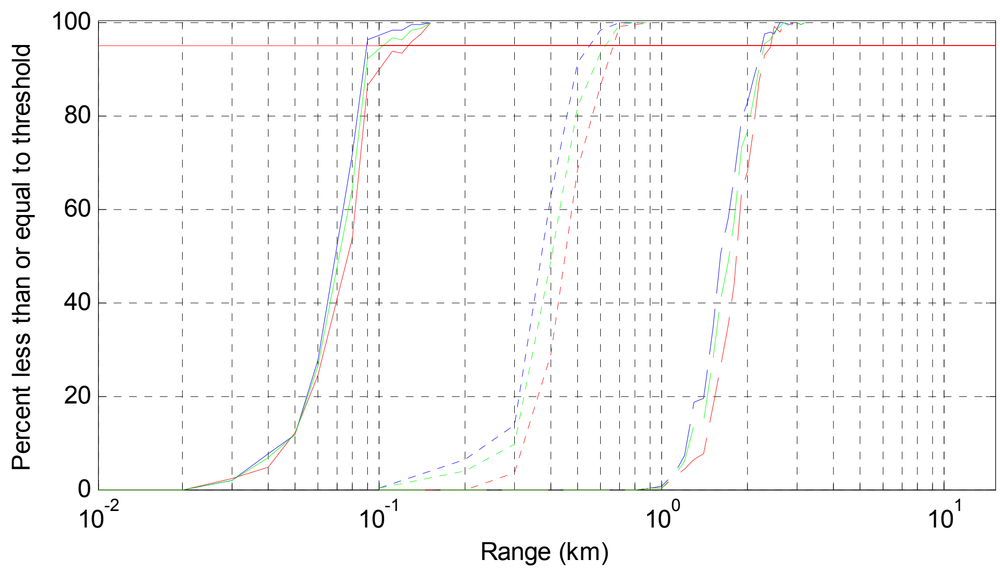

Figure 16. Percent of received levels less than or equal to threshold as a function of range for source points P1 and P2. Thresholds are: 160 dB re 1μPa (solid lines), 150 dB re 1μPa (dotted lines), and 140 dB re 1μPa (broken lines). Data from source point P1 is in blue, P2 is in red, and combined data from P1 and P2 is in green. The horizontal red line shows the 95% threshold.

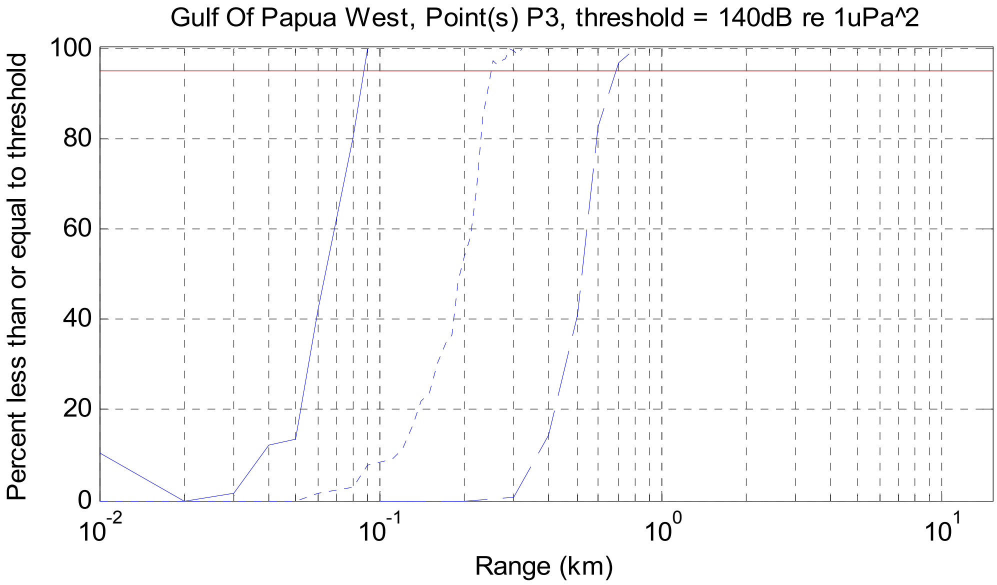

Figure 17. Percent of received levels less than or equal to threshold as a function of range for source point P3. Thresholds are: 160 dB re 1μPa (solid lines), 150 dB re 1μPa (dotted lines), and 140 dB re 1μPa (broken lines). The horizontal red line shows the 95% threshold.

4 Discussion

The probable noise field of the pipe laying vessel has been defined. The dominant underwater noise source is expected to be cavitation noise produced around the thrusters by the vessel holding position using its dynamic position system. While other underwater noise sources will exist there are no measurements of such and it is expected that cavitation noise will be the dominant noise source. Modelling of the likely underwater noise produced by the pipe laying vessel holding position indicated:

- That the vessel will be audible for > 20 km at all sites (with audible considered to be the vessel noise greater than a background broadband noise level in the 'normal' range of 95-110 dB re 1μPa). Note that defined outside detection ranges, as given by the signal reaching ambient noise levels were not calculated precisely in this study.
- That the range at which a broadband noise level of 140 dB re 1μPa was estimated to be reached varied from 700 m from the vessel at the source at the western end of the pipe route to 2200-2300 m at the eastern end of the pipe route.
- That the range at which a broadband noise level of 150 dB re 1μPa was estimated to be reached varied from 260 m from the source at the western end of the pipe route to 560-680 m at the eastern end of the pipe route
- That the range at which a broadband noise level of 160 dB re 1μPa was estimated to be reached was approximately 100 m. Note that the modelling exercise, by necessity, considers the source to be a point in space. In reality this is not the case, the source is spatially distributed across the vessel dimensions plus some portion of the bubble plume around the vessel. Hence the higher levels experienced (ie. > 160 dB re 1μPa) can conservatively be considered as occurring approximately within 100 m of the vessel extent.

It is believed that broadband noise levels above approximately 180 dB re 1μPa are required to produce detectable physiological effects such as temporary hearing threshold shifts (variety of workers, summarised in Richardson et al 1995). Given that predicted broadband noise levels are < 180 dB re 1μPa even at close range to the vessel, then it is probable the pipe laying vessel will not be capable of causing physiological effects to marine animals. This leaves potential environmental effects as:

- Attraction to the source
- Avoidance from the source at some range
- Masking of signals of interest
- Possible increase in noise induced stress for animals which linger in the area.

The frequency content of cavitation noise is broad band, that is it has energy spread over a remarkably wide range of frequencies. Highest noise levels will likely occur in the 10 Hz to several kHz range but there will be significant energy in the higher frequencies, up into many tens of kHz. This will make the pipe laying vessel audible to a wide range of marine fauna, including toothed whales which hear best in higher frequencies (optimal range for species likely to be in the area is 20-80 kHz) and great whales (optimal hearing sensitivity < 1 kHz).

The pipe laying vessel will be a static or slowly moving source. This mitigates avoidance effects which involve an animal deviating to avoid vessel collision. Sources which are continual and do not move favour marine animals readily acclimating to them.

Attraction

It is possible that the pipe laying vessel will attract some marine animals. There have been recent experiments which have shown that many late stage larval fish are attracted to relatively non-specific broadcast sounds emulating reef systems (Simpson et al 2005). It may be possible that similar attraction of larval fishes to the vicinity of the pipe laying vessel may occur.

It may also be possible that the fixed pipe laying noise will attract whales. The noise will be detectable typically at many tens of km depending on the prevailing background sea noise conditions (noting that for a signal to be discernible amongst the background noise it needs to be a few dB above the ambient conditions). It would not be inconceivable that some whales are attracted to the vessel noise out of curiosity or that through time the vessels become considered by resident animals as “landmarks”.

Avoidance and behavioural effects

The estimated noise levels calculated indicate that when the pipe laying vessel is working an approaching marine animal may detect the facility at around many tens of km. If the wind picks up then the range where the vessel is clearly audible will drop. Although the vessel may be audible at potentially long ranges its noise will not be greatly above background noise conditions. As the animal approaches the vessel the underwater noise will become more intense and perceived by an animal as louder. But, it would not be until the animal is within perhaps 1-2 km of the pipe laying vessel that the signal could be considered to be 'loud', as indicated by the 140 dB re 1μPa level.

Richardson et al (1995) have summarised many workers findings on the response of great whales to noise. Several features emerge from this summary:

- there is definitive evidence of behavioural responses of great whales to various noise sources
- the type of response is variable, and ranges from none to active avoidance of a source;
- there is evidence that at the species level whales respond differently to a given noise depending on their gender, behavioural state and habits at that particular time;
- there is evidence that the response of a species to man-made noise may change through time due to familiarisation or sensitisation of whales to the noise source

Richardson et al (1995) summarises several workers observations to, and experimental playbacks of, petroleum drilling and associated industrial noise to mostly gray and bowhead whales. Their summary states "*that stationary industrial activities producing continuous noise result in less dramatic reactions by cetaceans than do moving sound sources, particularly ships*". They noted that some cetaceans approached industrial noise sources to close range, and that the radius of avoidance of these sources was considerably less than the radius at which the source was audible. Richardson et al (1995) present summary tables of the broadband levels at which avoidance occurred in various observations and experimental trials, and present the level at which 10% of migrating gray whales avoided a semi-submersible drilling rig as 114 dB re 1μPa, 50% avoidance at 117 dB re 1μPa and 90% avoidance at > 128 dB re 1μPa. For spring-migrating bowhead whales passing drilling operations they estimated strong behavioural changes at levels near 124 dB re 1μPa and typical closest approach to levels of 131 dB re 1μPa. Using the 130 dB re 1μPa value as an estimate of avoidance ranges for the pipe laying vessel under its DP operating state gives 90% avoidance ranges from the vessel at 1 km (western end of pipelaying route, curves Figure 15) to 10 km (towards eastern end of pipe laying route, Figure 15).

Perhaps the best long term study of whale response to vessel approaches is that of Watkins (1986). He reports on more than 25 years of observations made of whales and vessels in the vicinity of Cape Cod, on the eastern US seaboard. Watkins (1986) reported that over the years the response of minke and finback whales to nearby vessels changed from frequent positive responses to uninterested reactions, the response of northern right whales did not change and humpbacks changed from mixed, often negative encounters, to generally positive responses. Given the time frame of the pipe laying operations will be months and the pipe laying barge will move slowly then it is unlikely that resident marine fauna will have time to acclimate to the point of positive responses to the vessel, although they may acclimate to its nearby presence.

Watkins (1986) stressed that the most vigorous whale responses came from noise sources that changed suddenly, rapidly increased (such as an approaching vessel) or were unexpected. He also noted that whales that were preoccupied with some activity were less responsive than whales that were inactive. Richardson et al (1995) reiterates this in his summary of baleen whale responses to vessels, stating that when vessels approach whales slowly and non-aggressively the whale response is similar, whereas rapidly changing vessel noise often resulted in strong avoidance responses from nearby whales. McCauley et al (1996) estimated the underwater noise level received at humpback whales involved in whale watching encounters and simultaneously measured their behavioural reactions. The most vigorous responses consistently came from vessels which either produced the most erratic noise levels with many sharp increases in level, or which had deliberately approached whales too closely (tens of metres).

The noise of the pipe laying vessel in DP mode, while relatively intense, has the redeeming feature in that it is produced by stable platforms which either do not move, only move slowly, or whose movements are independent of any nearby whales (ie no deliberate approaches). The noise is also predicted to be reasonably constant in nature, that is there would normally be few sharp changes in noise level with time. Watkins (1986) and McCauley et al (1996) have shown that rapidly approaching or rapidly increasing noise may constitute a threat to whales and that vessel noises which are erratic and involve many sharp changes in level over short time scales are more likely to cause adverse behavioural reactions.

Hence it is probable that under normal activities nearby marine mega fauna will be aware of the pipe laying vessel from tens of km, and may approach it to approximately 1-10 km. Given the continual and constant nature of the noise it is probable that some resident animals may quickly habituate and the noise will not produce any startle or alarm types of response.

Masking of signals of interest

When a signal (marine animal call) cannot be detected by a listener because of the presence of noise (potentially the pipe laying vessel noise) then the noise is said to mask the signal. The masking of signals is a complex function which involves understanding how an animal hears in the presence of noise and the character and level of the masking noise and the signal of interest. Most vertebrates are particularly good at filtering out noise so as to detect weak signals of interest. Although little is known about the hearing capabilities of whales, their extensive use of sound and the high and variable natural levels of natural background noise in the sea, suggest that they have highly adapted capabilities for detecting signals in noise. For masking to occur the most important factors are the relative locations of the sender, receiver and masking noise source, the frequency content and level of the primary signal, the frequency content and level of the masking signal and the ambient noise regime at the time.

The nature of the pipe laying vessel noise when it is operating in DP mode is for continual noise over a wide frequency bandwidth which is intense at the source. This is the worst scenario for masking noise since it implies there are no time brackets free of masking noise, an animal cannot rely on using a comparatively wide bandwidth signal to avoid masking since the masking noise is also wide bandwidth, and the noise levels are high for relatively long ranges around the source. We have not attempted to calculate masking ranges for different marina animal sources and receivers around the pipe laying vessel as there are too many scenarios to consider. But, when analysing long data sets of sea noise it is typical that much larger numbers of low level signals are detected than higher level signals. This is a function of sound transmission in the ocean and the squared increase in area available as the range increase. An example of this is shown on Figure 18, where the received level of pygmy blue whale detections in the Perth Canyon is shown (data of McCauley). Assuming that there will be many more long range and thus low level signals transmitted between marine animal groups, then it is probable that for a marine animal 'near' to the pipe laying vessel considerable masking impacts will occur. "Near' the pipe laying vessel depends on the proximity of the transmitting source of interest, but could be into tens km from the pipe laying vessel for say a great whale listening for distant (tens km away) co-specifics.

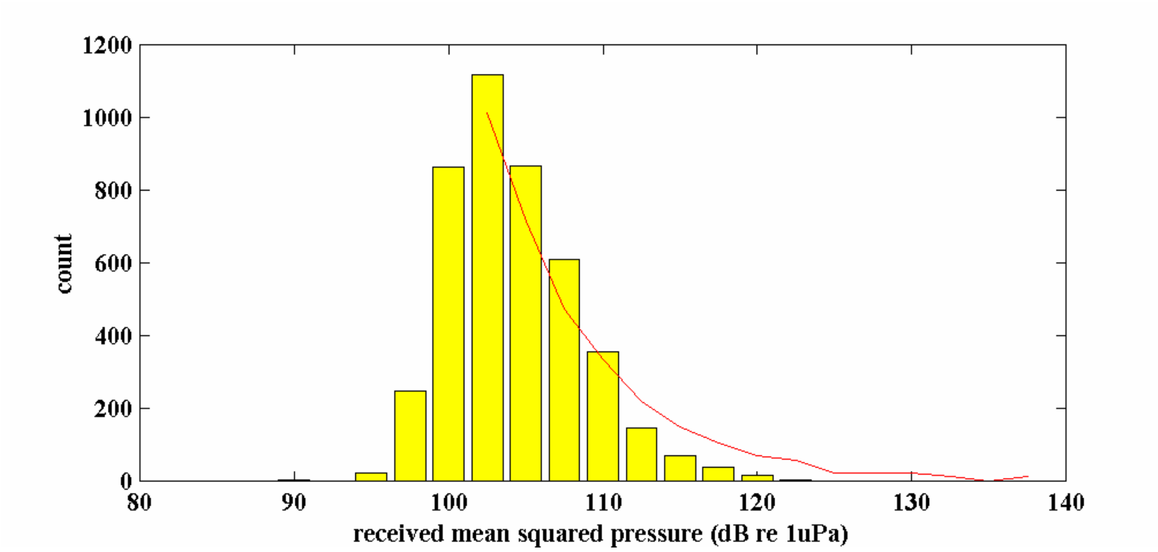

Figure 18. Distribution of received pygmy blue whale type II components heard in the Perth Canyon in 2000.

5 Conclusions

In summary,

- Underwater sound levels produced during the pipelaying operation are expected to be dominated by noise produced by the vessel's thrusters while on dynamic positioning.

- The muddy seabed in the western part of the pipeline route will result in the sound levels reducing much more rapidly with range in this region than over the sandy seabeds found in the eastern portion of the pipeline route.
- The sound levels produced by cavitation of the pipelay vessel thrusters are predicted to be too low to produce detectable physiological effects, such as temporary hearing threshold shifts, on marine animals, except perhaps in the immediate vicinity (within a few metres) of the propellers.
- Cetaceans will be aware of the pipe laying vessel from tens of km, and may exhibit avoidance behaviour at ranges of between 1and 10 km, with the smaller distances corresponding to the western end of the pipeline route, and the larger distances to the eastern end.
- Given the continual and constant nature of the noise it is probable that some resident animals may quickly habituate and the noise is unlikely to produce any startle or alarm types of responses.
- The most significant effect of the noise is likely to be increased masking of relatively low level signals transmitted between groups of marine animals.
- Should an anchor vessel be used, rather than a DP vessel, then the highest noise levels would be expected to occur during anchor handling operations, and would again be dominated by propeller cavitation noise. The levels would depend on the details of the anchor handling operations but would be expected to be somewhat less than those produced by a large DP vessel. In addition, these high noise events would occur over relatively short time periods.

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Annex B

Infauna Results

Species	Broad Classification*	Site																							
		1	3	5	7	10	12	14	17	18	20	23	26	27	28	30	32	34	36	37	38	40	41	42	44
Porifera indet	Porifera																		1						
Hydroida sp 1	Cnidaria Hydrozoa																							1	
Hydroida sp 2	Cnidaria Hydrozoa																				1				
Hydroida sp 3	Cnidaria Hydrozoa																		1						
Hydroida sp 4	Cnidaria Hydrozoa																		1						
Edwardsiidae sp	Cnidaria Anthozoa																		1						
Nemertean sp 1	Nemertean	1	1	1			1								1	1						1			
Nemertean sp 2	Nemertean																								1
Nemertean sp 3	Nemertean													1											1
Nemertean sp 4	Nemertean	1		1						1				1											
Oligochaete sp	Annelida Oligochaete					1			2																
Polychaete Indeterm	Annelida Polychaeta																		1						
Sternaspis scutata	Annelida Polychaeta	4												3			1								2
Cossura sp.	Annelida Polychaeta	2															1								
Magelona sp	Annelida Polychaeta	1										1										2			
Orbiniidae sp 1	Annelida Polychaeta																4						2	3	
Spio Sp 1	Annelida Polychaeta						1		1			1		1	1				1			2	1	3	
Spio Sp 2	Annelida Polychaeta											1										1	2		
Spionidae indeter.	Annelida Polychaeta								1			2		1											1
Pseudopolydora sp 1	Annelida Polychaeta								1						1									1	1
Pseudopolydora sp 2	Annelida Polychaeta																		1						
Dispio sp	Annelida Polychaeta															1									
Prionospio multicristata	Annelida Polychaeta		2											1											
Prionospio sp 1	Annelida Polychaeta	4																						1	1
Prionospio sp 2	Annelida Polychaeta						1																		
Prionospio sp 3	Annelida Polychaeta																1	1							
Prionospio sp 4	Annelida Polychaeta																							1	
Orthoprionosio sp	Annelida Polychaeta						2																		
Polydorella sp	Annelida Polychaeta						1																		
Poecilochaetus sp	Annelida Polychaeta																		1						
Opheliidae sp 1	Annelida Polychaeta	1										6													
Opheliidae sp 2	Annelida Polychaeta																							1	
Glyceridae sp 1	Annelida Polychaeta	2																							
Glyceridae sp 2	Annelida Polychaeta																1								
Maldanidae sp	Annelida Polychaeta	1																							
Ampharetidae sp	Annelida Polychaeta	4							1																1
Hesionidae sp 1	Annelida Polychaeta	2		1																					
Hesionidae sp 3	Annelida Polychaeta						1									1									1
Hesionidae sp 4	Annelida Polychaeta								1																
Hesionidae sp 5	Annelida Polychaeta												1												
Hesionidae sp 6	Annelida Polychaeta													2		1	1							1	1
Hesionidae sp 7	Annelida Polychaeta														1		1								
Hesionidae sp 8	Annelida Polychaeta																							1	
Hesionidae sp 9	Annelida Polychaeta																								1
Syllidae sp 1	Annelida Polychaeta		2						1																
Syllidae sp 2	Annelida Polychaeta		2																						

* Classifications: Porifera = Phylum, Cnidaria = Phylum, Hydrozoa = Class, Anthozoa = Class, Nemertean = Phylum, Annelida = Phylum, Oligochaete = Class, Polychaeta = Class.

Species	Broad Classification*	Site																							
		1	3	5	7	10	12	14	17	18	20	23	26	27	28	30	32	34	36	37	38	40	41	42	44
Syllidae sp 3	Annelida Polychaeta								2			4													
Syllidae sp 4	Annelida Polychaeta													1					1					1	
Aglaophamus sp	Annelida Polychaeta									1				1								2	2		
Flabelligera sp 1	Annelida Polychaeta																				1			1	1
Flabelligera sp 2	Annelida Polychaeta																							1	
Notomastus sp	Annelida Polychaeta																		2						2
Lumbrineridae sp	Annelida Polychaeta														2						2				1
Lumbrineridae sp	Annelida Polychaeta																		1						
Lumbrineridae sp	Annelida Polychaeta						1					1													
Cirratulidae sp 1	Annelida Polychaeta		8																1						
Cirratulidae sp 2	Annelida Polychaeta																							1	
Hipponia sp	Annelida Polychaeta																		1						
Aricidea sp	Annelida Polychaeta		1				1	1							2		1		1			1			
Oenonidae	Annelida Polychaeta						1	1	1			2													
Terebellidae sp	Annelida Polychaeta								2						1	1									
Sigalion sp	Annelida Polychaeta	1	2																						
Sigalionidae sp	Annelida Polychaeta																1					1		1	
Mediomastus sp	Annelida Polychaeta		1																					1	
Barantolla sp	Annelida Polychaeta								1								5								
Notomastus sp	Annelida Polychaeta																						3	4	
Nereididae sp	Annelida Polychaeta														1										
Ostracod sp 1	Crustacea Ostracoda		4																						
Ostracod sp 2	Crustacea Ostracoda								1																
Ostracod sp 3	Crustacea Ostracoda																	1						1	
Ostracod sp 4	Crustacea Ostracoda																		1						
Ostracod sp 5	Crustacea Ostracoda																							1	
Ostracod sp 6	Crustacea Ostracoda																								3
Mysidae sp	Crustacea Ostracoda																		1						
Cumacean sp 1	Crustacea Ostracoda				1																			2	
Cumacean sp 2	Crustacea Ostracoda																1								1
Cumacean sp 3	Crustacea Ostracoda																		2						
Cumacean sp 4	Crustacea Ostracoda																								1
Agathotanaididae sp 1	Crustacea Tanaidacea																								1
Anuropodidae sp 1	Crustacea Tanaidacea																								3
Kalliapseudidae sp 1	Crustacea Tanaidacea													1			2					1			
Kalliapseudidae sp 2	Crustacea Tanaidacea															2							2		
Kalliapseudidae sp 3	Crustacea Tanaidacea																		1						2
Kalliapseudidae sp 4	Crustacea Tanaidacea																		1						
Kalliapseudidae sp 5	Crustacea Tanaidacea																								1
Sphyrapidae sp 1	Crustacea Tanaidacea								1															5	
Tanaidacea sp 1	Crustacea Tanaidacea						2					1												6	
Tanaidacea sp 13	Crustacea Tanaidacea																								1
Tanaidacea sp 15	Crustacea Tanaidacea																							1	
Tanaidacea sp 16	Crustacea Tanaidacea																							1	
Tanaidacea sp 3	Crustacea Tanaidacea													2	1			1							
Tanaidacea sp 8	Crustacea Tanaidacea																		2						

* Classifications: Annelida = Phylum, Polychaeta = Class, Crustacea = Subphylum, Ostracoda = Class, Tanaidacea = Order.

Species	Broad Classification*	Site																							
		1	**3**	**5**	**7**	**10**	**12**	**14**	**17**	**18**	**20**	**23**	**26**	**27**	**28**	**30**	**32**	**34**	**36**	**37**	**38**	**40**	**41**	**42**	**44**
Tanaidae sp 1	Crustacea Tanaidacea																		1						
Anthuridae sp 1	Crustacea Isopoda	1			1				1					1			2		1					1	1
Anthuridae sp 2	Crustacea Isopoda			2																					
Gnathia sp 1 & 2	Crustacea Isopoda						1							1											1
Gnathia sp 2	Crustacea Isopoda																								
Ampeliscidae sp 1	Crustacea Amphopoda		3		2		2					3		5					3					3	8
Ampithoidae sp 1	Crustacea Amphopoda													1											
Caprellidae I	Crustacea Amphopoda			1															1						
Corophiidae sp 1	Crustacea Amphopoda			1			1		1					2		1			2						
Corophiidae sp 2	Crustacea Amphopoda	1																							
Corophiidae sp 3	Crustacea Amphopoda																		1						
Cyproideidae sp 1	Crustacea Amphopoda																1								
Eusiridae sp 1	Crustacea Amphopoda			4					1					7		8						2	1	12	
Hyalidae sp 1	Crustacea Amphopoda																		2						
Ischyroceridae sp 1	Crustacea Amphopoda	2		2											1		1								
Leucothoidae sp 1	Crustacea Amphopoda													1					1				1		
Phoxocephalidae spp	Crustacea Amphopoda		6				1					1		2										2	1
Amphipoda sp 10	Crustacea Amphopoda																1							1	
Amphipoda sp 14	Crustacea Amphopoda																		2						
Caridea indet.	Crustacea Decapoda	1															1								
Hippolytidae sp	Crustacea Decapoda								1																
Palaemonidae sp	Crustacea Decapoda													3			1								
Ogyrides delli	Crustacea Decapoda													1											1
Alpheus spp	Crustacea Decapoda																1							1	
Callianassidae spp	Crustacea Decapoda								1										1			2	2	6	
Stomatopoda spp	Crustacea Decapoda		1		1																				
Decapoda indet.	Crustacea Decapoda								1					2											1
Brachyura sp	Crustacea Decapoda														1										
Phoronida sp I	Phoronida			1			1		1						2	1			3						
Phoronida sp II	Phoronida															1						1			1
Tellinidae sp 1	Mollusca Bivalvia	1	1																						
Tellinidae sp 2	Mollusca Bivalvia		1																						
Veneridae sp 1	Mollusca Bivalvia		6																						
Veneridae sp 2	Mollusca Bivalvia																		1						1
Ringicula sp	Mollusca Gastropoda		1																						
Gastropod sp 1	Mollusca Gastropoda						1																		
Nassarius sp 1	Mollusca Gastropoda		2																						
Nassarius sp 2	Mollusca Gastropoda																							1	
Holothurian	Echinodermata													2					1						1
Ophiuroid	Echinodermata		2					1	1					3		1	1	1	2					3	1
Echinoid indet	Echinodermata													1					2		1		1		
Gobiidae sp 1	Osteichthyes																		1	1					
Gobiidae sp 2	Osteichthyes		1											1											
Gobiidae indet.	Osteichthyes											1													
Brachymblopus sp	Osteichthyes																					1			

* Classifications: Crustacea = Subphylum, Tanaidacea = Order, Isopoda = Order, Amphopoda = Order, Decapoda = Order, Phoronida = Phylum, Mollusca = Phylum, Bivalvia = Class, Gastropoda = Class, Echinodermata = Phylum, Osteichthyes = Class.

Multidimensional Scaling Results